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THE ART AND CRAFT OF CABLE JOINTING

A BOOK FOR MAINS ENGINEERS CABLE JOINTERS AND STUDENTS

BY

C. G. WATSON
M.I.E.E.

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TO

MY FATHER,

CHARLES WATSON,

WHO TAUGHT ME TO ASK

HOW ? WHEN ? WHERE ? WHY ?

PREFACE

LEST any reader think that I am satisfied with this work, I have to say that it is but the shade of what I wish it to be. Nevertheless, I send it forth to a wider public than my own immediate circle, because it fulfils, at least partly, a need; and because, notwithstanding its many defects, it has proved useful during the instruction of those concerned with jointing: the engineer, the draughtsman, the jointer, and the mate.

And lest any think that my unaided efforts have made this book, I, while alone responsible for the contents, have to record my indebtedness, and express my thanks, to Mr. H. S. Blomeley for the drawings which so greatly enhance whatever value the text may possess; to Mr. S. E. Clotworthy for comment throughout; to Mr. S. Harrop for calculation of the tables; to Mr. W. Maskery for help with lead work; and to all those who, at one time or another, have contributed towards my knowledge of the subject.

THE AUTHOR.

GARRIGILL
1927

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THE ART AND CRAFT OF CABLE JOINTING

CHAPTER I

INTRODUCTORY

ART, Engineering, Science: a descending scale of values, human values, of course.

Art results from the unconscious co-ordination of innumerable and, so, indefinite factors to the creation of a thing satisfactory to man's aspirations: the thing may be a building, a song, a way, an idea, a dish, or even the pot the dish is cooked in; but, whatsoever it may be, the artistic thing is consonant with the efficient.

Science is the reasoning co-ordination of few and definite factors to a unity.

Engineering combines the methods of Science with the inspirations of Art. That is to say, engineering allows a definite end to be achieved partly in a scientific and partly in an artistic way.

But, what has all this to do with Cable Jointing?

Nothing?

No, surely not!

Here: Cable Jointing is a part of engineering, a part, moreover, where the indefinite exceeds the definite, a part where the problems to be solved are not subject to an invariable solution, and a part, therefore, peculiarly susceptible to personal idiosyncrasy.

In so far as cable jointing is based on observed and invariable fact, it is scientific, definite, and admitting of no variation. But in so far as it is empirical, as largely it is, it is artistic, relies on the personality of the designer for its efficiency, and thus is a medium for individual expression: each problem is solved according to the designer's judgment, a judgment based partly on his experience and partly on the innate qualities of his mind.

The extensions and qualifications of the argument just outlined are so numerous that it would require many a page simply to state them ; but no more need here be remarked as we are not primarily interested in the matter, and as enough has already been said to outline the point of view underlying all that follows.

So, progress can now be made to my subject :

Types of Cables Dealt With.

The intention herein is to describe the operations of cable jointing and to relate certain conclusions pertaining to three core, paper insulated, lead sheathed, and wire armoured cable joints. In thus limiting the scope, it is hoped that little of value to the designer or constructor of joints will be omitted, for what is applicable to a three core joint will, with obvious exceptions or extensions, be applicable to other joints.

First, a brief survey of the field to be covered will be made. Then, each of the main divisions of the subject will be treated in detail. And then, a description of the making of a complete joint will be given. Such procedure involves some repetition, but as it possesses the advantage of giving a conspectus of the whole before considering the parts, and as the parts are subsequently summed up in the whole, its merits overbalance its disadvantages.

The Need for Simplicity.

It is to be taken as axiomatic that simplicity of design is an essential of sound practice. That this is far from being universally recognized is shown, for example, by the occasional practice of seemingly trying to put within a joint as varied an assortment of materials as possible. Such practice is indefensible. Of course, the reply that is made to criticism of this sort is that the practice has given little trouble. Whether or not the truth of the reply is borne out by facts, it is needless to inquire, but it is necessary to remark that while trouble is a positive criterion of failure, want of trouble is purely negative and does not prove that a more satisfactory practice is impossible: experience is limited and should not be allowed to outweigh general considerations without proof of their insufficiency. Instead, it may be that careful attention to such considerations would lead to a practice giving no more trouble and, at the same time, be more economical of labour or material, or of both, than a practice based on caprice. However, it must not be supposed that neglect of experience is here advocated. By no means is that the case. All that is here intended is to remind the reader that the human mind is capable of solving many problems without recourse to direct experience; and that only when there is no other guide, as will sometimes happen, should experience of a particular case be followed; and even then, allied experience should receive full consideration.

Further, on the assumption—surely a permissible one—that a cable is so constructed as to perform the work required of it in the most efficient way ; and as, when extending any work, imitation of the existing work is desirable, especially when that work has proved itself eminently adapted to its purpose, so it would appear that the design of a joint should follow the design of the cable to be jointed. And, because a cable, made as it is under favourable conditions, is more likely properly to fulfil its functions than is a joint made, more often than not, under adverse conditions, so, other things equal, that design is to be preferred which involves least disturbance of the cable.

The One-man Job.

Also, it is essential that each joint, from the cutting of the cables to the completion of the sealing, should be made by one man, as in this way pride of workmanship is fostered and good work likely to result, whereas for two or more men to have a hand in the one joint divides responsibility and so leads to carelessness. Therefore, the time taken to make a joint is limited by the endurance of the jointer. One other aid to the designer is this : where other means of settling proportions are absent, beauty is a useful guide, for man has so much inbred knowledge, and so much knowledge acquired in so many and so varied ways as to be as unconscious as the inbred, that beauty is not only aesthetic but practical.

Bases of Design.

The matter may be put more shortly thus: the bases of design should be simplicity, an attention to general considerations with a freedom from an overwhelming regard for particular precedent, imitation and least disturbance of existing work, and appearance.

The second and last two bases call for no further remark, but the others do, for the ideas both of simplicity and imitation have to be applied discreetly. That is to say, a barbarous simplicity and a slavish imitation are to be avoided, for it is probable that in any particular case the simplest or the most imitative solution is not the best one, as each case presents points of greater or less variation from the general which call for special treatment. To illustrate the one, take the case of those joints in which the bare conductors were enclosed in a box filled with compound and no other insulation whatsoever: this was certainly simple, but it was not efficient, in so much as use of the method led to trouble. To illustrate the other, take the case of those joints which were insulated with mica: that practice was imitative, because it was copied from a practice in use for an allied but other purpose. It was not, however, efficient for cable jointing.

Secondary bases are to be economy of time and economy of material. But, in order that undue weight should not, in the first place, be given to these economies, it is to be remembered that they will more than possibly result from a nice attention to the primary bases. It is also to be remembered that the jointing problem is not to design and to make a joint to withstand any condition, but so to design and so to make that the joint will withstand working conditions to the same extent as the cable it is to be used upon. Anything less is waste. Anything more is waste, too.

Problems to be Overcome.

The difficulties of jointing are largely due to the surroundings amid which joints are made. Thus, in general, joints are made in the open, where the weather has to be contended with, and where conditions are variable, and not in the seclusion of a workshop where all things are under control. Also, the practical necessity to keep dimensions within workable limits leads to problems distinct from the simple insulation of a conductor to withstand a given pressure. Beside, jointing depends on the jointer, because, although attempts have been made to eliminate the human element, machinery has not been developed capable to carry out the operations.

Altogether, the chief problems in cable jointing are connected with the exclusion of moisture, dirt, and air, and the prevention of voids. But, if a joint is to work satisfactorily under all the conditions met with in electric distribution, great attention should be paid to every detail, and efficient results will be attained only by clear and creative thought on the designer's part, and manipulative skill on the part of the jointer.

From what has been already said, it would be logical to suppose that only such materials as are present in the cable are to be used in the joint, and that such materials are to be distributed in the joint as in the cable. And, in fact, in the better designs, such materials only are used and only so distributed—except for slight variations which necessity or reasoned expediency justify. Thus, solder is used to sweat the conductors—a practical necessity ; and cotton tape for binding, even for insulating—a matter of expediency, but the departure from simple imitation in this case is justified by the fact that cotton is mechanically stronger than paper and so more fit to the purpose, and sufficiently like paper in its other properties as not to lead to trouble in the parts where it is used, or to offend an artistic sense of unity.

Position of Joint.

In designing a joint, the first matter to be considered is the situation in which the joint has to be made: Is there plenty of room, or is there not ? Is the joint to work in a fiery mine, in an unusual position, or in any place where peculiar construction is necessary ? It is needless to ask whether or not the joint has to work under water, for it is to be taken for granted that all joints should be so designed and so made that immersion in water is not detrimental to their efficiency.

Other Factors.

Also, the question of climate and of the men who will have to make the joint have to be taken into account. Thus, a design which is suitable for making in a dry climate and in a clear atmosphere may be quite unsuitable in a fog-ridden land or in the soot-laden air of a manufacturing town. And, a method which is satisfactory when operated by men of one nationality, or, what comes to the same thing, by men of one temperament, may be most unsatisfactory when operated by those of another.

On the whole, the best joint is that which occupies the least space, and that which will satisfy the greatest number of conditions, subject, of course, to proper allowances having been made in the design and construction for safe and reliable operation, and sound and efficient workmanship.

Workmanship.

This matter of workmanship deserves attention: Why should the aim not be to raise jointing into a craft? a craft in which all that is done has a meaning, a sound reason for its being, and not something done just out of ignorance or caprice; a craft in which nothing but what is essential is done, and nothing likewise that is essential is left undone: a craft in which nothing is adventitious, but all by design, and design, too, not for the workman unable to differentiate between sound work and shoddy, and so ready for any shift to get his task done, but for the craftsman who loves his work because interested in and appreciative of its niceties. To design so as to allow for errors is pretence, the art of the botcher.

The more important a point is, the more often shall I permit myself a repetition. And so, still further to elucidate, a conversation will now be recorded: A draughtsman, a designer, and an engineer were discussing joints. The first, in reply to the question, "Why do you show two inches of lead sheath projecting within the sleeve?" answered, "I don't know, but it is always done." The second had an explanation. It was this: To guard against bad plumbing. That is to say, to ensure a compound seal to the cable, so that, should the wipe be faulty, water would not penetrate to the interior of the joint. It was the latter, too, who objected to a lead sleeve being tapered because the tapering cut down the quantity of compound around the crutch, but why a large volume of compound was

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needed round the crutch, he was, when pressed, unable to explain. The third man, notable more for directness than suavity, and animated by a spirit like to my own, a trifle derisively, perhaps, yet quite good-naturedly, laughed and said, " In days when the commercial rule the roost, and when they are doing their best to corrupt the soul of man with the deceits of luxury, the whole question of design resolves itself into one of cost, first cost, and so you, having to earn a living, do well to copy practices which have not proved harmful; but, I think, a use of the imagination, although not too free a use—where to draw the line is a matter of judgment—so, I will say, a proper use of the imagination may be fruitful of improvements. For myself, I believe, in spite of the fact that the artist is considered as an incapable visionary and banished to the background of dreamland, and the craftsman valued no more than the coarsest workman, that art and a responsible sense of cost are closely allied. But there! I see that you are bored. So, I stop."

The least diameter of a cable joint is obtained by stepping the conductor joints as shown in Fig. 1, and the shortest length by arranging all conductor joints centrally between the two crutches, as shown in Fig. 2. But, as it is axiomatic that so little of the cables to be jointed should be disturbed as is fit to the case, so, as a general rule—a rule which in practice seldom need be broken—cables should be jointed with the conductor butts all midway in the length of the joint.

Jointing Procedure.

Jointing operations may conveniently be divided into those concerned with (1) the conductors; (2) the

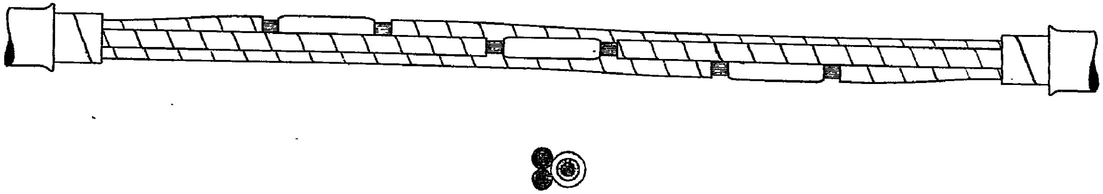


FIG. 1. STEPPED CONDUCTOR JOINTS

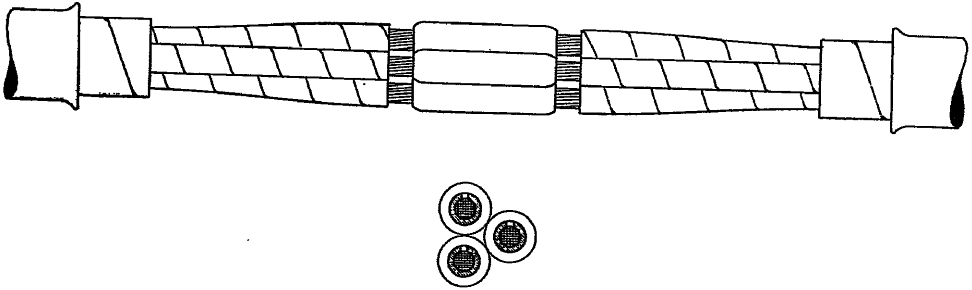


FIG. 2. CENTRAL CONDUCTOR JOINTS

insulation; (3) the sheath, and (4) the armour. Under those headings and in that order, I shall deal with them, firstly, as has already been stated, in a preliminary survey, then, in detail.

Conductors. 1. Where every operation is important, it is, perhaps, out of place to emphasize one more than another. Nevertheless, as there may be degrees of importance, it may be contended that the nearer the part to the centre of the joint, the more important is the operation concerned with that part. So, the most important operation of all may be said to be the sweating; then, the insulating; next, the plumbing; and last, the fixing of the outer cover. Whether or not the contention be correct, it is certainly very important that the conductors be soundly joined. Of the ways in which that may be done, three deserve mention. They are these: by lapping; by using a ferrule; by using braid. The last is to be specially noted, because its high tensile strength makes it nicely adapted for use in those situations, and they are many, in which expansion and contraction of the conductor occur; but when those processes are extreme, as, for instance, in colliery districts, the only way to avoid rupture of the conductor is to allow for its movement. One way in which that may be done is by means of an expansion joint.

Insulation. 2. The part of a joint upon which most time and ingenuity have been spent is that of the insulation, but to enumerate, let alone describe, all the ways that have been proposed, or even used, would be both tedious and needless. Therefore, all that I shall attempt to deal with are those ways possessing the merit of being simple and the quality of being imitative.

They may be divided into two groups, one in which paper, the other in which cotton, is the mainstay.

From the principle of imitation, it would naturally be supposed that paper should be used to insulate the jointed conductors. And so it is. But, exactly to imitate the cable by wrapping paper tape round the conductors is impracticable under the circumstances governing jointing, for not only does the wrapping take much time, but, in order that the imitation may be approximately complete, the insulation of the cores has to be stepped, or tapered, for such a distance that the tapering takes up much time, too. Beside, unless delicately handled, paper tape will crinkle ; its tensile strength is low, so permitting but slight strain to be applied in the wrapping, with the consequence that looseness of the tape results in imprisonment of air between the layers ; and a long exposure to a possibly humid and dusty atmosphere detracts from its value as an insulator.

However, paper in the form of tubes made of wrapped paper of similar thickness, and impregnated with a similar compound, to that used in cable manufacture, presents a material at once easy to handle and closely akin in its form, as well as in its matter, to the cable insulation. (Solid walled tubes of paper pulp have been used, but, although simple, they are only imitative in their matter and lack the dielectric strength of laminated tubes.)

But, paper tubes, in order to fulfil their function to the best advantage, need to fit neatly the core insulation, and so to be specially made for each size of cable. That is a disadvantage. Therefore, where conditions permit, that is to say, for cables having working pressures up to 12,000 volts, a form of insulation possessing the merit of being readily adaptable to any size of cable deserves consideration. Such an insulation is cotton tape impregnated, as in the case of the tubes, with a compound similar to that contained in the cable. Apart from the simplicity and imitativeness of using such a compound, there are other reasons for its use, and they are that it is by no means certain that, if different compound were used, it would coalesce, or its electrical properties would usefully mix with the cable compound, for it may well happen that two compounds either of which by itself would be satisfactory, would, if used in conjunction, not share the stress in the way which geometrical considerations alone would indicate.

If it were possible to exclude all air from between the bunched insulated cores, they could be enveloped by wrappings of paper or cotton tape to the requisite thickness, and the joint completed by forming a sheath directly upon them. But while, doubtless with much care and patience, it might be possible so to pack the spaces between the cores with impregnated yarn or paper that little air would be imprisioned, yet the practical difficulties of so doing would be exceedingly great. Therefore (and because of one other factor, later to appear), another method of completing the insulation has to be adopted. This might consist in securely binding together the bunched cores with one or more belts of paper or cotton tape, enclosing the whole within a sleeve, and in filling that with compound. But, the introduction of compound within the sleeve involves problems of its own which have to be surmounted by slightly altering the method of binding the cores together. In fact, the cores are kept apart, so that air can escape and compound enter between them.

For reasons similar to those given in the second preceding paragraph, it is advisable that the compound used to surround the main insulation of the joint should be similar to that used to impregnate the cable and joint insulation ; and in cables for working pressures of 20,000 volts and over, such a compound is imperative. But, thin sleeve filling compound is liable to leak from the joint into the cable and so necessitates an arrangement of the sleeve such that a reservoir of compound is present to make up for the leakage. So, for pressures up to 12,000 volts, a more viscous compound presents advantages.

The Sheath. 3. Because the joint insulation is similar to the cable insulation, so, in like manner to the cable, should the joint insulation have a waterproof covering ; and because the cable covering (the sheath) is of pressed lead, so should the joint covering (the sleeve) be of pressed lead. And, in order that a relatively unhurtful path may be afforded whatever currents may be in the lead, as well as for the purpose of making waterproof connection between the sheath and the sleeve, the two should be joined together by a plumb. Therefore, it will be seen that those joint boxes of wood, earthenware, iron, and other materials, with or without bonding arrangements, are not proper solutions of the problem: they are commercial makeshifts, or needless complications, and so will not further be mentioned herein.

Armouring. 4. To carry the rule of imitation to a logical conclusion would necessitate wrapping round the sleeve a waterproof serving and armour wires as in the cable, but to do so would be a long and, at its best, a doubtfully efficacious proceeding, especially in the matter of bonding. So, a method of protection is adopted which answers all the purposes of the serving and the armour, and answers those purposes efficiently. That method is to enclose the joint sleeve in a cast-iron box to which the armour is securely clamped at each end, and to which the sleeve is bonded. And, in order that water shall not collect with possible deleterious effect on the sleeve, the box is filled with waterproof compound.

Need for Practice.

The reader will not become a jointer or an engineer simply by poring over my pages. Practice is essential for both. Therefore, let him take a length of cable, a length of lead pipe, and the sundry materials needful to make a joint; let him take a kit of tools, and let him make a joint, two joints, many joints: by the time he has perfected his technique, he will have extended his knowledge of the design and construction of joints to a surprising extent, for words, useful enough as they are to indicate a method, will not give that skill which only practice can.

The Ideal Jointer.

Pursuing my plan, which is to separate each section from the next by a page or two of lighter matter, I will here say a few words on a matter of moment and one which, were I treating the subject in strictly significant order, should have had its place at the very beginning: In jointing, as in every other human activity, the man is of prime importance. In passing, it may be observed that this importance is due to his ability to improvise, to create. Therefore, it is well that a jointer's qualifications be defined : A jointer is a clean, careful, and intelligent man who, as a mate from the age of seventeen, has served a five years' apprenticeship to the trade, and who, during that apprenticeship, has attended evening classes or made such studies as opportunity permitted.

One of those automatons turned out by a factory in a month to do a particular job, is not a jointer, but only one more of those machines which are yearly being evolved to destroy all workmanship, all pride, all love of work as an expression of oneself, for all he can do is to make one special kind of joint in one special way under one special condition. A jointer is a mechanic who will tackle with confidence any joint, anywhere, any time, and make a sound job. Such a man is not made in a month, or from a man selected at random. Rather, he should be selected by an engineer after a sample joint has been made. Then, if that is satisfactory, let him make low-tension joints; then, let him make high tension joints; and then, when he has gained that confidence in himself which is as necessary in the intelligent as disastrous in the ignorant, let him make joints for the highest tensions.

At the moment there are not enough highly-skilled men for the work that has to be done. There never will be unless interested firms engage and keep suitable youths as jointers' mates. Even if they started to do so now, it would be many years before there was a sufficient supply. A temporary measure, however, would be to engage mechanics who have already had a training in one or the other trade, and to give them an intensive schooling in jointing. There are surely plenty of such men about who would be glad of the chance. At present, a deterrent to the training of jointers is the risk there is of losing them and the consequent loss when they leave the trainer; but if all contributed to their training, all would benefit, no matter whether a man left one firm to go to another or not. Therefore, why should not the cable companies and the large supply companies, in fact, all those interested in sound jointing, combine to institute a jointing school, and thus equitably to distribute the cost of training jointers ?

About Tools.

In addition to the man, his tools call for comment, because, although it is quite true that a poor workman blames his tools, yet it is also true that a good man can do better work with good tools than he can with poor ones.

Jointer's tools should be of the best quality obtainable and should be single purpose tools. That is to say, they should not comprise a spanner combined with a hammer, or pliers with gadgets for twisting and cutting wire, gripping pipes, screwdriving, and levering, or a knife with a hundred and one blades; for combination tools, while the joy of the schoolboy, are a source of annoyance to the skilled man.

CHAPTER II

LAPPED JOINTS AND FERRULE JOINTS

Tents and Joint Holes.

Now, I am about to consider the design and construction of joints in detail. First, however, it will be well to point out that the joint hole should be of ample dimensions. The tent should be of ample dimensions, too. In fact, there should be two tents, one to cover the joint hole, and one to cover the tools and material. Also, when there is a likelihood of much rain or seepage, the hole should have a sump in one corner, and a pump should be mounted above ground on that side of the tent remote from the opening ; beside which precautions, the hole should be floored with wood in order to prevent splashing. Another matter deserving notice is this: all the operations of jointing should be conducted with great care. And, not only care, but with knowledge, too. Knowledge that water, dirt, and air are inimical to the satisfactory working of a joint. And not only that knowledge, but knowledge of how to compass the end in view in the best way.

How not to Make a Joint.

As care is generally recognized as a desirable quality, it is needless to enlarge upon the point, but as the need of knowledge, in connection with jointing, has not general recognition, an incident to enforce this point will be in place. So : An engineer, conscientious and persevering, set out to supervise the jointing of a long cable by a jointer, also conscientious and persevering. Each joint was carefully made and carefully inspected. But, soon after the cable was put into commission, the whole of the joints had to be remade. Why? Why, because the engineer, having his head as well as a pocket book stuffed with formulae, more or less acquaintance with electric theory, experience of machine construction, and even of cable making, had no knowledge of jointing. (Let it not be thought that either the engineer or theory is to be belittled. By no means: both are useful, but both are more useful when experience guides the one, and practice reinforces the other.) Consequently, his supervision was to him to be a lesson, a lesson which, unhappily, his underling was ill-equipped to teach, for the jointer was a labourer promoted in an emergency to make a low tension joint, and, by dint of luck, to make high tension joints, too. And what were the joints like? Like this: Conductor joints stepped, but as the ferrules overlapped, the stepping was robbed of all meaning. The conductors had been poked into the ferrules, all very neatly and carefully; but, while the holes in the tops of the ferrules had been filled with solder, yet the conductor strands were quite destitute of that consolidating alloy; and, as tool marks plainly showed, surplus solder had been removed by a file. Over the ferrules, tape had been wrapped to a great thickness, again, all very neatly and carefully, but so great a thickness had been wrapped that the insulated cores touched the sleeve; and a greater fault, the tape had that dark colour characteristic of overheating, and its fetidity confirmed the evidence of sight. The sleeves were well plumbed to the sheaths, and so gave that appearance to the completed joints which, no doubt, accounted for their maker's reputation as a good jointer; but, under the plumbs, holes in and sagging of the sheath showed that metal had been poured on by a generous but unskilled hand. And, inside the sleeve, deep hollows in the compound, and surfaces pitted with craters. And, all was due to lack of proper knowledge.

The Prime Causes of Failure.

Upon a fault occurring in a joint, the usual assumption is that the source of the trouble lies in the insulation. Why that should be so is not clear, as it is equally possible that the trouble is rooted in the conductor, for experience has taught that faulty sweating of conductors has been responsible for very many breakdowns and that, unless the conductor joint be soundly made, no amount of insulation will avail to prevent failure. These are reasons, reasons making strong appeal to the practical engineer, why great attention should be paid to proper soldering, and why I shall devote many pages to a description of methods of conductor jointing.

"Lapping" the Conductors.

When material for jointing otherwise is not available, conductors may be "lapped" in this way:

Taking nineteen strand conductors as an example, let the two to be joined overlap three inches. Turn back the outermost layer of strands on each conductor three inches from the ends. Sweat solid the exposed seven strand centres; saw one and a half inches off each end; butt the new ends and keep them in position by soldering the butt. Cut off one of the outer strands of one conductor at the point where it is turned up; lay the corresponding strand of the other conductor neatly on to the sweated centres so that it just meets the strand that has been shortened; cut off three inches from the strand next the one that has already been laid upon the centres, and lay the corresponding strand of the other conductor alongside the one already in position. Proceed thus until all the strands are laid up. Bind the whole of the laid up strands together tightly, closely and evenly with tinned copper wire, say of 20 gauge, from half an inch beyond one set of outside butts to a similar distance beyond the other set of butts. Solder, and a solid mass of conductor is obtained but slightly exceeding in diameter that of the untouched conductor. The nearly finished joint and one stage in its making are illustrated in Fig. 3.

For conductors having more than nineteen strands, the inner nineteen should be treated as just described, except for the binding, and succeeding layers of strands should be laid up as the outside layer of the nineteen strand conductor, with an additional half-inch of interlace at each end in each layer over the one within it, and bound overall as in the preceding case.

That process, while sound and as nearly imitative of the cable conductor as the conditions permit, is a lengthy one and entails disturbance of the conductor. So, because time is an important factor in jointing, and because disturbance is to be avoided, it should not be used when it is practicable, as generally it is, to use one of the methods about to be described.

Use of Ferrules.

Because of the comparative ease with which it can be made, the conductor joint most commonly used is that wherein the ends are inserted into a slotted metal tube, the ferrule, and the whole consolidated by pouring in molten solder: a seemingly simple matter. Nevertheless, the design and construction of ferrule joints need thought and care.

Imitating the conductors, the ferrule should be made of annealed drawn copper. And, to avoid overheating, it should possess equal conductivity. So, the metals being alike, the cross-section of the ferrule metal should equal that of the conductor metal: the loss of conductivity due to the slot and to the slight increase of bore needed to enable the ferrule readily to slip over the conductors, may be balanced against the gain due to the butting ends. To fix the length of the ferrule, the assumption may be made that one hundred amperes per square inch is a safe rating for soldered contacts.

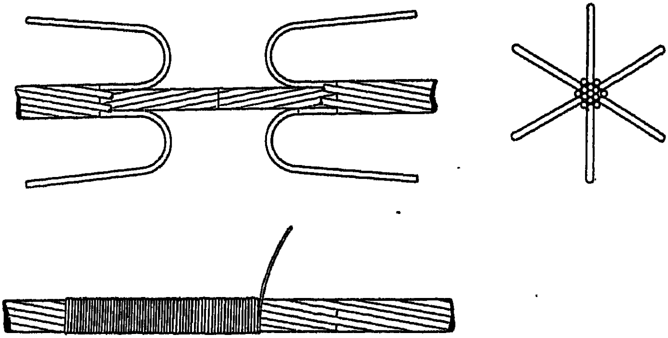


FIG. 3

Putting these conclusions into formulae, the principal dimensions of the ferrule are—

$$D = \sqrt{\frac{A + \cdot785d^2}{\cdot785}}$$

and $$L = \frac{2C}{100 \times 3\cdot14d}$$

where D = overall diameter of ferrule ;

A = cross-sectional area of conductor ;

d = diameter of conductor ;

L = length of ferrule ;

and C = current to be carried by conductor ; the bore being from one to two mils, but never more than five mils, greater than d.

To permit of the proper flow of solder into the ferrule, a slot, or a row of holes, of a width equal to one-fourth of the conductor diameter and extending to within half an inch of each end of the ferrule, should pierce its wall.

In high tension joints, where it is important that no detail should be neglected that will conduce to the best result, advantage should be taken of our present knowledge of the incidence of dielectric stresses, and the ferrule rounded by a full curve, which, by the by, also gives approximately the economical shape from a conductivity standpoint ; but in low tension joints such rounding is practically needless, although all rough edges should be removed in order to prevent injury to those having to handle them. In medium pressure joints, say, for joints on cables having working pressures from one to twelve thousand volts, where the expense involved in machining the ferrules to the full curve is not so needful as in higher pressure joints, the ends may be rounded to a radius not less than that of the conductor they are to be used upon. This permissible case is illustrated in Fig. 4b, and the other cases in Figs. 4a and 4c.

In making ferrule joints, the conductors to be joined should first be sweated solid (when circular sectioned ferrules are to be used upon delta conductors, the latter should first be rounded. This may readily be effected by squeezing the core with pliers before removing the paper); then inserted into the ferrule so that they butt at its centre, and then the whole consolidated by pouring in hot solder until it flows freely from the ends of the ferrule; and cooler solder until the whole of the ferrule and conductor becomes one solid mass and the slot is filled with solder to the level of the outside of the ferrule wall.

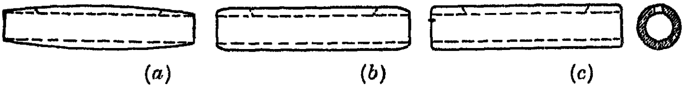


FIG. 4. FERRULES

The dimensions resulting from the use of the formulae given on the preceding page, relate to ferrules for circular stranded conductors. For delta conductors, the diameters, inside and outside, should be slightly larger owing to the difficulty there is of rounding the conductors in order to make them enter the ferrule. Because of that difficulty, and because, when tubes form the insulation, of the necessity to have an even surface, it is preferable to have ferrules for delta conductors shaped similarly to, and bored so that they neatly fit the conductor. Such ferrules are more costly to manufacture than circular sectioned ones, but as they involve no disturbance of the cable conductor, so they ensure a sounder joint, and save time in its making. However, both expensive ferrule and difficulty of rounding may be avoided by the use of the method next to be described.

Strength of Ferrules. The tensile strength of a ferrule joint of the length needful to suffice for electrical considerations is much less than that of the unbroken conductor. Therefore, in situations where the conductors are liable to be subjected to tensile stress, a stronger form of joint is desirable.

Such situations occur more commonly than is usually recognized, in fact, in all cables carrying loads which vary from day to day, expansion and contraction of the conductors take place, especially so in large low-tension cables carrying heavy currents. Also, there is the expansion and contraction due to seasonal variations of temperature. That the internal stresses set up in the cable conductors by temperature variations are negligible is disproved by experience. In fact, many instances could be cited in which the conductors had completely left the ferrule. No doubt, when cables are drawn into duct lines whose manholes provide for bends in the cables therein, the expansion and contraction due to temperature changes are taken up by the bends; but in cases where long straight lengths are installed, as, for instance, where cables are laid direct in the ground, consideration should be given to stresses likely to be set up in the conductors by heating and cooling of the cable. The rupture of the joint by such stresses could, doubtless, be overcome by the use of a long lapped joint, or even by a long ferrule; but, as short joints are to be preferred to long ones, a method of conductor jointing which reduces the length while retaining the strength presents advantages.

CHAPTER III

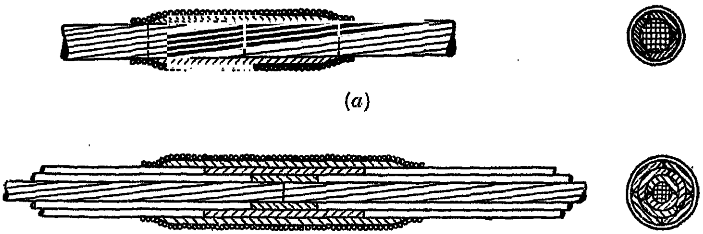
BRAID JOINTS AND EXPANSION JOINTS

Braid Joints.

In order to meet the need for a conductor joint possessing high tensile strength as well as high conductivity, Mr. Charles Vernier, than whom no engineer has taken greater pains to improve cable jointing, invented the Braid joint. This is illustrated in Fig. 5a, and consists of strips of braided fine gauge copper wire laid lengthwise on the conductors to be joined, bound with binding wire over their entire length, and the whole soldered. The flexible braids compress closely into all the crevices between the wires forming the outermost layer of the conductor, so that copper to copper contact is large. So much so, that an unsoldered joint requires the exertion of much force to pull out. Further, delta and circular conductors can be joined equally well with braid, as it readily adapts itself to their shape, which is retained throughout the joint.

Soldered joints made in this way have a tensile strength approximating very closely to that of the conductors up to a cross-sectional area of ·15 sq. in.; but larger conductors, in order to obtain similar tensile strength, should be joined as shown in Fig. 5b, from which it will be seen that each layer of wire in the strand is stepped back and the spaces so formed filled with braids which are finally bound and soldered as before. This second type of braid joint, applied to large conductors, is particularly well suited for work where soldering is prohibited, for it may remain unsoldered and still retain good conductivity.

A satisfactory braid joint is made as follows: The ends of the two conductors to be joined are separately soldered solid and butted. While still hot from the soldering, a little solder is poured over the butt and the conductors wiped clean. (This soldering of the butt is not essential, but it is a helpful jointer's trick to keep the conductors in position during the subsequent operations.) Lengthwise across the butt, strips of braid of the appropriate weight and length, after shaping, are laid and lightly hammered until their edges meet around the circumference and their ends gently slope to the conductor. Tinned copper wire of suitable gauge is then bound tightly, closely, and evenly over the whole length, beginning on the conductor at one end and finishing on the conductor at the other end.



(*a*)

(*b*)

FIG. 5. BRAIDED JOINTS

Then, the whole is soldered. In soldering, let the metal be clean and hot, and let there be plenty of it: simply to pour a ladleful of dirty or just molten solder over the binding wire is useless, for such will not penetrate to the inside, and a joint is obtained which, as well as being externally unpleasing, will heat when current approaching the capacity of the cable flows, and disaster follows. Therefore, pour over the joint ladleful upon ladleful of hot, clean solder until it is judged—experience only will enable a right judgment to be made—that the whole joint is thoroughly hot and that metal has penetrated into all the crevices. Then pour cooler and cooler metal until the whole is about to solidify. And then, quickly wipe the joint and adjacent conductor with a fine, clean rag in order to remove unwanted metal. Never use a file for that purpose. Again, never use a flux containing acid or salts, as either may cause subsequent damage by corrosion. Rather, use only resin as a flux. Or, with recalcitrant copper, use the paste obtained by heating and mixing together five parts of resin to two of palm oil.

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Preparation of Solder.

As it is of the utmost importance that solder should be clean and correctly proportioned, it is proper here to describe a method ensuring both: Heat in an iron pot, well bedded in a coke fire so that the heat is as evenly distributed as possible, so much lead as is needed to make the amount of solder required, which amount should be only what will suffice for, say, a week's work. On the top of the molten lead, place a few lumps of sulphur of the size of a walnut and, when they have melted, mix lead and sulphur thoroughly, and skim any dross that forms from the surface. Add sulphur until dross ceases to form. Then, add a lump of tallow, and mix well with the lead. And then, add a lump of resin and mix again. The result will be a clear silvery

621·31934 3573
N27

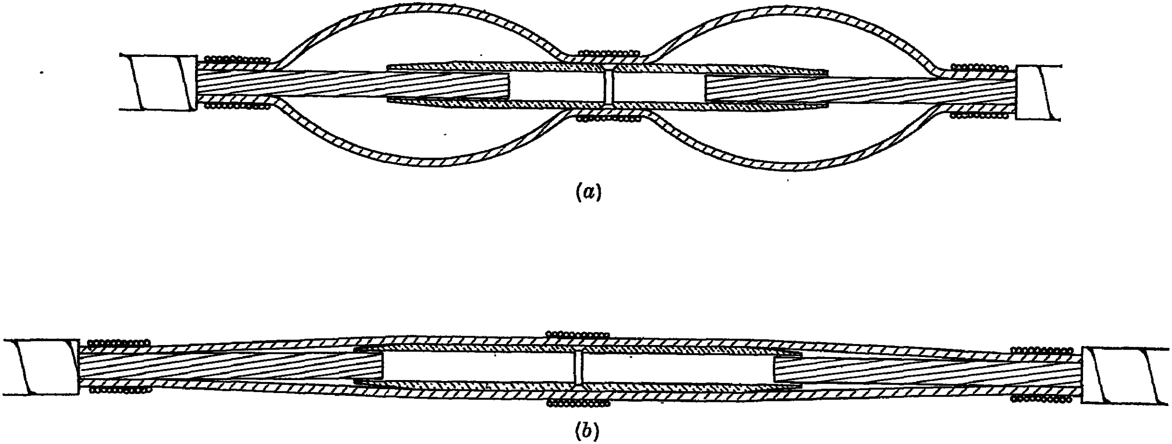
liquid. Weigh it, and add twice its weight of tin. Stir well and the solder is ready for use. These rules apply equally as well to lapped and ferrule joints as to braid joints, and their observance will ensure a joint solid throughout, and smooth on the outside. So, satisfactory as a conductor and as a bed for the insulation.

Because of its adaptability, the braid joint is to be preferred for the jointing of delta-shaped conductors in all cases, and, because of its high tensile strength, for the jointing of circular conductors when tensile stresses are likely to be a source of trouble ; but its high conductivity and simplicity are greatly in its favour under all circumstances.

Expansion Joints.

Before leaving conductor jointing, mention must be made of the only expansion joint which has given proof over a long period of its suitability for the purpose for which it was designed. Others have been proposed, even used, but the Vernier Expansion Joint is the one meriting attention. In this joint, the two conductors to be joined slide within a brass tube having centrally and externally attached two or more copper braids whose ends are sweated to the conductors beyond each end of the tube. The joint is illustrated in Fig. 6a, which shows the relative positions of the parts as installed ; and in Fig. 6b which shows the positions at maximum expansion. To reduce the stress in the insulation, this joint may be surrounded by a copper tube well rounded at the ends and electrically connected to the conductor.

It must not be supposed that such a joint will


(a)

(b)

FIG. 6. VERNIER EXPANSION JOINT

altogether prevent trouble arising from expansion or contraction. At the most, it is a delaying accessory, which will fulfil its purpose so long as the expansion is not extreme, and its useful field is in districts where subsidence is common.

CHAPTER IV

INSULATION

Insulating the Joint.

To insulate the jointed conductors is essentially a simple process, the chief requirements being care and cleanliness: care should be taken that all material is of the right quality, and that it is dry and clean; and care should be taken, too, that the jointer's hands are dry and clean. With those precautions, an inexperienced but sensible man can acquire the little skill needed efficiently to perform the operations after a few attempts; although, of course, the more the practice, up to the limit of a man's aptitude, the greater the skill.

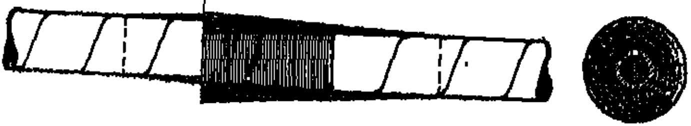
At the outset it must be said that no perfect way to insulate a joint has yet been discovered: all ways are subject to difficulties, the chief difficulty in every case consisting of that of excluding air and its contained moisture from within the sleeve.

Before dealing with the eminently practical, I must note that the most truly imitative joint is that in which impregnated paper tape is wrapped round the parts to be insulated. Anterior to the wrapping, the core insulation is tapered for a length equal to thirty times the thickness of the insulation round the core. "Oh! But," I heard, "what a sharp knife that would need!" Thereat, having myself learnt the process only the day before, I laughed (inwardly, of course). Why? Why, because there is a method of tapering which is so pretty, so neat, so rarely adapted to its end, that, were it not that time is an important limitation to joint making, there would be little need to seek further for a means of insulating a joint. The method which so arouses my admiration is this: With a wire so chosen that one, two, or three diameters gives the advance needed, the core is bound with one or more turns of wire at the point where the top of the slope is to be; then the outermost layer of paper is unwrapped from the core and torn off close to the binding; butting against the preceding turns, one, two, or three, according to the slope required and to the size of wire being used, turns of wire are bound closely and evenly round the core denuded, as it has been, of one layer of paper; then, the next layer of paper is unwrapped and torn off; again, one, two, or three turns are bound close against the preceding turns and another layer is unwrapped and torn off; and so on until the conductor is reached. In that way, a regular taper, or stepping, of the insulation is obtained. But, pretty though it be, being, as it is, the inverse of the tapering process, the wrapping of impregnated paper tape round the parts so prepared is a long and monotonous task affording many loopholes for subsequent trouble.

A drawing of a core insulated in the way described is, however, given in Fig. 7.

Exclusion of Air.

From the standpoint of simplicity, imitation, and ease of manipulation, paper tubes impregnated with oil are a form of insulation presenting many advantages. (Here and hereafter, unless the context clearly imply that a distinction is to be made, "oil" signifies the material used to impregnate a cable during its manufacture.) They may be applied either directly in



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contact with the jointed conductor and core insulation, or a space may be left between the inside surface of the tube and the core. In the one case, the attempt is made to exclude air at the time the tube is being placed in position. In the other case, the attempt is made subsequently to drive out the air, but this method has difficulties of its own which, it is true, have been, at least partially, overcome by various means, that is, by vacuum pump exhausting, by canting the joint, by filling from the bottom, by forcing compound through the joint, and by combinations of these, all of which add considerably to the cost of jointing. Beside, the use of loose tubes necessitates a scaffold within the sleeve for their centralization, and gives to the construction that appearance of clumsiness, often of flimsiness, which is indicative of poor design. So, the former method is the one to be preferred, because it is the simpler, and because experience has shown, at any rate for pressures up to 20,000 volts, that as good results can be obtained by its use as in the other way. However, a process which involves no expensive apparatus, no alteration of joint design, and ensures the exclusion of air and moisture from the joint insulation, is that whereby the whole of the insulating operations are carried out under oil. Such process has been put only to experimental use, but there appears to be no valid reason why it should not be extensively adopted, and it is here advanced as a practicable method for use in conjunction with tubular insulation.

In all cases of the use of paper tubes, the surface of the core and conductor joint should be in alignment for the full length of the tube. To make it so, a ferrule having similar external dimensions to the insulated cable core is permissible, but it is preferable that the jointed conductor should be lapped with impregnated cotton tape until the length upon which the tube will bed is smooth and straight.

Paper Tube Insulation.

Of the ways in which paper may be applied in tubular form I will mention four:

1. *The Tapered Roll Method.* The one permitting ot least dimensions is beautifully simple; but, like many other simple things, it was the last discovered. This may be owing to the simple being the outcome of a new idea, whereas the complex, that is, the relatively complex, is no more than the combination of previously known things. Be that as it may, the inventor, whoever he may be, of the tapered roll which is wound on to the core without touch of hands, except on the outermost layer, deserves all praise. In fact, I admire this method so much, both because of its form and because of its manner of application, that I consider its inventor a genius. After so much commendation, it will, perhaps, be expected that a weird and wonderful contrivance is to be disclosed. But no, not at all; for, as I have already said, the matter is so simple as may be. It consists of this: A sheet of paper of appropriate length (the length varies with the size of the conductor and voltage of cable—in fact, it varies from a few feet to many tens of feet) is cut lengthwise so that it tapers from a width equal to that of the maximum length of tube, that is, the length of the tube bedding on the core, at one end of the sheet to a width equal to the length of tube of maximum diameter at the other end; half of the difference between the two

widths being equal to the length of the taper at each end of the completed tube. The sheet is rolled on to a tubular former having a diameter approximating to that of the core to be insulated, and is impregnated and dispatched to the site in sealed tins. There, it is wound on to the core by passing the outside end of the roll round the roll and the core, and then unwinding by turning the former with the fingers. When all is unrolled, the former is withdrawn, the inside end of the roll held on to the core so that the completed tube will lie symmetrically, and the roll tightened by continued turning of the outermost layer until the whole is a thoroughly compact tube, tightly bedding on and surrounding the jointed conductor and adjacent parts of the core insulation. A core insulated in this manner is illustrated in Fig. 8. However, in particular, there is one drawback to a tube so put on, and that is that air is almost certainly entrapped between the layers during the winding-up process. Were the wrapping on site done under oil, no better method of insulating could be desired. But, as the winding on in the way described is a proprietary process, and as it is well not to have to rely on such a process, an alternative method should be available. It is. It forms the subject of the next paragraph.

2. *The Slip-on Tube.* A form of paper tube which does not suffer from the drawback above mentioned is that wherein a tube, as in Fig. 9, is wrapped and impregnated in the factory all ready for slipping on to the core. In this case, the inside diameter of the tube should be slightly greater than the outer diameter of the core, so that the one will readily pass over the other. Before fixing these tubes in position, the jointed

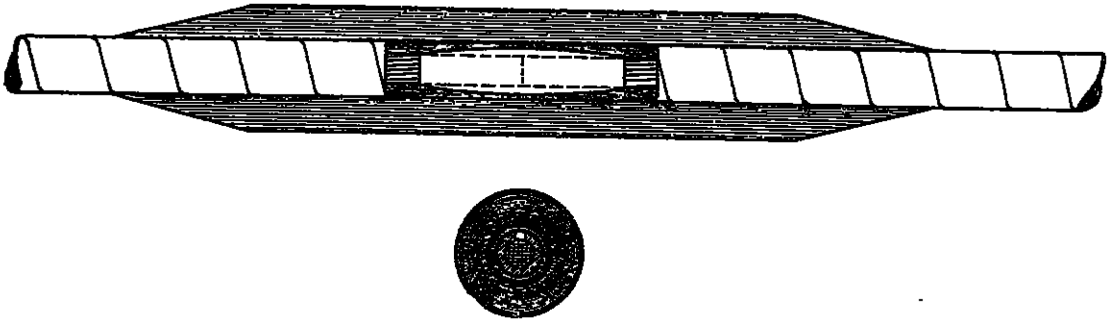


Fig. 8. Wound-on Tube

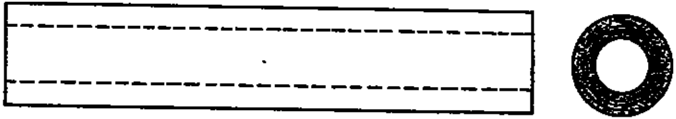


Fig. 9. Form of Slip-on Tube

conductor is made level with the core insulation, and the whole is taped with a fine impregnated tape to such diameter that the tube is brought over the parts to be insulated with difficulty, the parts having previously been well coated with oil. In this way, air is excluded from the inside of the tube—to some extent, at least. The drawback to this form of tube is that the tubes have to be slipped over the cores before the conductors are jointed, and so the length of the joint has to be much more, and so more cable has to be disturbed, than otherwise would be the case; notwithstanding that, this tube is the one best suited to our purpose, especially so when slipped, as it may be, into its final position under oil. As, however, meaningless corners are as abhorrent to the engineer as to the artist, so should they be eradicated from the tubes by tapering the paper of which the tubes are made. And so a core insulated in this way appears similar to a core insulated with a tube of Form 1. To make the matter quite clear, in Fig. 10 is given a drawing of a tube in position.

3. *The Slit Tube Method.* Another form of paper tube is that in which one composite tube is made up of a number of component tubes each having a wall not exceeding one-eighth of an inch in thickness, in order that it may readily compress either on to the core or on to the component tube beneath it, and each slit lengthwise for convenience of assembly, in which operation the slits are staggered so that a long creepage path exists between the inner and outer surfaces of the composite tube. Previous to placing the components in position, each is smeared with oil so as to ensure as far as practicable the exclusion of air and

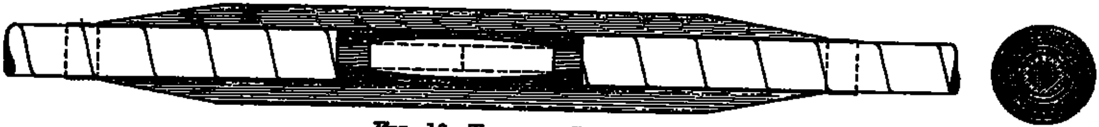


Fig. 10. Tapered Slip-on Tube

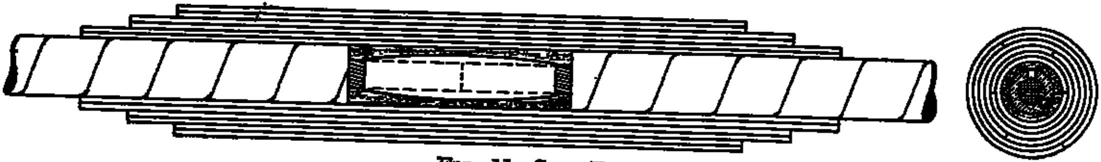


Fig. 11. Slit Tubes

the adhesion of one to another. However, these tubes, illustrated in Fig. 11, although in their time extensively used, are awkward to fix, and the partial destruction necessary to place them in position is objectionable. So, in spite of the short joint their use permits, they are not to be recommended.

4. *Another Method.* Yet another method, see Fig. 12, would consist of short and long tubes alternately assembled, so that no straight path existed from conductor to conductor through the junctions; but as this arrangement presents no outstanding advantage over other methods it has not been used.

General Notes.

Anchoring. The tube that is rolled round the jointed conductor on site can be put on so tightly that it will not slip, but other tubes need to be anchored. This may effectively be done by wrappings of impregnated cotton tape at the ends of the tubes, as shown in Fig. 13.

Paper Tube Dimensions. The dimensions of the tubes, owing to the lack of definite information relative to their strength, largely depend upon the designer's judgment, for such tests as are possible, being carried out, as mostly they are, on joints made in all the security of an experimental laboratory, where it is impossible adequately to reproduce the risks from snow and rain, wind and dust, and the general discomfort of the jointer, all of which are complemental to jointing in the trench, are a guide only and not definitive: all that tests on sample joints do is to indicate the best results that are likely to follow when joints are made in the way and under the conditions of the test joints.

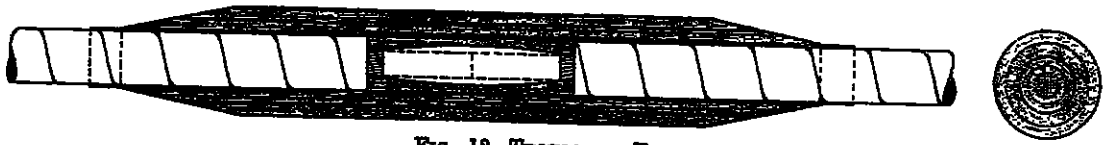


FIG. 12. TELESCOPE TUBES

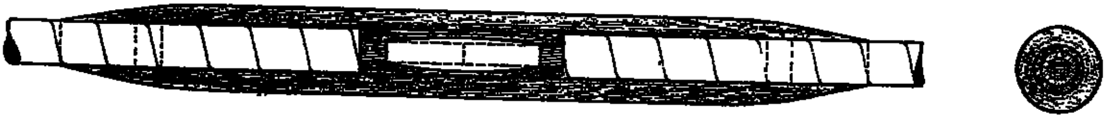


FIG. 13 ANCHORING OF TUBE

As individual judgment is the deciding factor, I can do no more than to give my own reasons for dimensioning joints. They are these:

The average breakdown strength of a layer of paper in a tube is not less than that of an average layer of similar thickness in the cable, for the tube paper being unbroken throughout its width has not those breaks existing in the cable paper. So, it is an assumption on the safe side to assume that equal thicknesses of tube insulation to cable insulation will possess equal strength. But an allowance has to be made for the difference between the conditions of cable making and the conditions of jointing. What that allowance should be depends upon the way the tubes are made and assembled. For tubes made in a factory and bodily slipped over the conductors, a fifty per cent increase of wall thickness will cover all the risks of outside work. (Of course, skilled workmanship is taken for granted. Really, it is not a technical matter when it becomes necessary to design a joint to be made by the unskilled. In fact, no reliance can be placed on joints so made.) For tubes wound on to the jointed conductor in air and so offering greater risk of inclusion of deleterious matter, an allowance of one-hundred per cent to cover all risks should be made. A seventy-five per cent allowance should be made for slit tubes—with this addition: one component tube, so that in any radial direction, there is a full wall of paper irrespective of the space left between the edges of the slits. Thus, a tube to insulate a joint in a cable having a core with ·1 in. paper wall, should have in case 1, ·15 in. wall; in case 2, ·2 in.; and in case 3, taking each component as having

1/16 in. wall, ·25 in. And a cable having a ·25 in. wall should have ·38 in.; ·5 in.; and with each component ·09 in., ·54 in. respectively. As the method of arriving at the thicknesses does not depend on a law deducible by a priori reasoning, but is a generalization resulting from experience, so also is the method used to calculate the length of the tubes: I recommend that the length of tubes to be slipped over the core in air should be based on a creepage allowance of 4,000 volts per inch of path. Other forms of tubes need to be longer, but all forms may be shorter when assembled under oil, in which case a creepage path of 6,000 volts per inch may be taken as perfectly safe. What the taper of the tubes should be, I have no definite information enabling me to decide, but my judgment is satisfied if the parallel part of the tube is as long as the distance between the cut faces of the core insulation plus one inch for each 8,000 volts of working pressure.

Because the close assemblage of the cores prevents oil from entering all the interspaces, cores insulated in any of the ways described should each be encircled, near to each end of the parallel part of the tube, to a radial thickness of one-tenth of an inch, by two bands of paper tape of 2 in. width. Then the three cores should be held together, after the interspaces between the bands have been filled with shaped wads of paper, by two belts of tape, over the bands, to a radial thickness such that the total thickness of band and belt is not less than the thickness of insulation round each jointed conductor, and such that the belt will touch the sleeve and so form a support for the cores. The bands and belts are illustrated in Fig. 14.

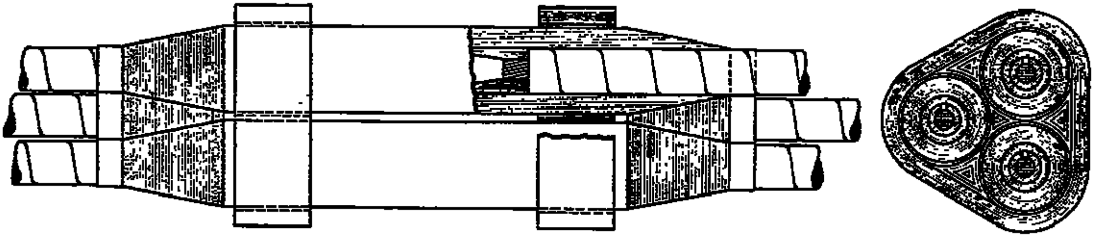


FIG. 14. BANDED AND BELTED TUBES

Use of Cotton Tape.

As has been aforesaid, the drawback to the universal use of tubes is the need of having them specially made for each size of conductor and each working pressure of cable, so an insulation which avoids that drawback and which is otherwise suitable, is one that possesses a practical advantage which cannot be neglected, and such an insulation is impregnated cotton tape, which has the additional, if slight, advantage that a shorter joint can be made by its use than by the use of tubes. This gain is owing to its flexibility and so to the needlessness of having a long straight core in the joint.

Limitations. As one joint should be made in one day by one man, and as the wrapping of sufficient tape to insulate a joint for more than 12,000 volts takes up more time than is available, so the use of tape is limited to joints of that and lower working pressures.

Preparation of Tape. Suitable tapes are finely woven cotton with a selvage, and 1½ in., 1 in., and ½ in. wide, and seven mils thick, which impregnation increases to ten mils. The impregnation may be done in the factory in a similar way to that in which the cable is impregnated, and the tape sent to the site in sealed tins and there, after winding into suitable rolls, reheated for such time as is necessary to remove all trace of moisture. That is the better way, as time is thereby saved on the site, but tape may be prepared by the jointer in the following way: Clean tape is wound, some in small rolls, some on copper strips, 3 in. × 1 in. × 20 gauge, or on pieces of hard wood 3 in. × 1 in. × ⅛ in., to an overall thickness of ½ in., and heated in a wire cage immersed in a pan of oil at a temperature of from 110° to 115° C.—the latter temperature should never be exceeded as the cotton starts to decompose thereabout. When bubbles cease to rise to the surface of the oil, the impregnation is complete, but the tape should be left in the oil until it is at such a temperature that it can be handled with ease. Any tape left over from one day may be reheated and used during the day following.

Tape so prepared is taken from the pan as required, and wrapped round the parts to be insulated, that is, the bare jointed conductor and such length of the core as will prevent creepage. To be exact, the length of the taping will not be less than would be the length of a paper tube for the same class of cable, and will taper gently to the core in order to avoid the slipping of the layers one over the other, and so give to the whole a neat appearance. It may be argued that the radial thickness of tape to be applied should vary with the conditions determining the cable walls. Thus, in cables where mechanical considerations are the factors governing the thickness of the insulation, the tape should be of similar thickness to the core wall; in cables where electric and mechanical factors combine to fix the core wall, the taping should have a radial thickness fifty per cent greater than that of the core wall; and, in cables where electric considerations preponderate, twice the thickness of tape should be applied; so, in cables for working pressures up to 1,000 volts, the tape should equal the paper wall; in cables for pressures from 1,000 to 3,000 volts, the tape should exceed the paper by half its thickness; and in higher voltage cables the tape should be twice the paper. But, as a simple all-embracing rule is better than particular directions for each case, so the rule for determining the thickness of tape should be "twice the radial thickness of the core paper."

Applying the Tape. Each core, having been wrapped tightly, closely, and evenly with half-lapped tape, should, in order to allow free passage for the flow of compound, be banded at its centre with tape 1½ in. wide to a radial thickness of ⅛ in. Then, a shaped wad of tape should be fitted into the central cavity between the bands, the cores squeezed together, wads placed in the outer crevices between the bands, and the whole held in position by a belt of tape wound over the bands to such thickness that the radial thickness of band and belt is not less than the thickness of tape round each conductor joint. A joint so insulated is shown in Fig. 15. The purist will use bands and wads on all occasions, but the practical engineer, aware that small quantities of air in joints working at comparatively low pressures have no detectably harmful effect, will use them only for joints for over 3,000 volts. However, there is a reason, a psychological one and one that was touched upon in the preceding paragraph, why the standard should be adhered to on all occasions. The reason is this: If exceptions are made, men will get into the habit of thinking that the process is not of importance and so be likely to omit it in joints where it does matter.

It may be noted that as a joint has not to fulfil the requirement of flexibility in the way that a cable has to, so it is permissible to increase the resin content of the compound in which the tape is boiled in order to increase its resistance to breakdown by electrostatic

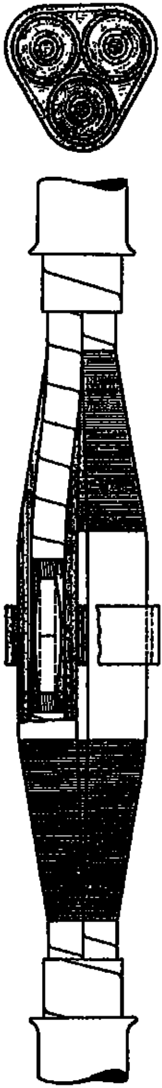


FIG. 15. TAPE INSULATED JOINT

stress; but as to do so increases manufacturing and jointing difficulties, it is not recommended.

Adding the Compound.

Although out of the order of jointing operations, yet because the compound used to fill the sleeve fulfils the functions of an insulator, albeit its primary function is to displace air, the filling of the sleeve with compound will now be discussed.

As conditions within the joint are comparable, even if not strictly identical, with the conditions within the cable, and as the interstices of the cable are filled with oil, so what more reasonable than to fill the joint interspaces with oil, too. And, if the oil in the cable is the most satisfactory material for its purpose, is it not also reasonable to suppose that a similar oil will be equally satisfactory in the joint?

It would appear so.

But, apart from purely logical reasons, there is a tangible reason for filling the joint with oil similar to that used to impregnate the cable: because, during operation, the cable temperature varies: sometimes it is hot, sometimes it is cold. Consequently, the oil within the cable expands and contracts. Some of the alteration of volume is taken up by the expansion and compression of the air within the cable, and the expansion of the sheath. But, the more perfect the cable, the less air will there be contained within it, and the more need will there be to provide room for expansion exterior to the cable. And what more convenient place to do this than in the joint? Therefore, and because it is clearly inadmissible to have different compounds within the one cable, the joint sleeve should be filled with oil similar to that present in the cable. But to provide a reservoir wherein oil is stored against the cable's need, involves a much larger, and consequently a more expensive, sleeve than otherwise would be needed.

The higher the rated voltage of the cable, the more care is there taken during manufacture to ensure complete impregnation. But, in cables rated up to 12,000 volts, enough air or partial voids exist to act as a cushion and so to prevent exudation of oil from the cable to the joint. So, joints on such cables may be without a reservoir.

But, owing to the fact that cables, when first laid and connected to a reservoir of oil, suck up oil, it is inadvisable to use a thin compound, such as cable impregnating compounds are, to fill the sleeve when no reservoir is present. Therefore, in such a case, a compound possessing properties directly to be outlined should be used.

The Ideal Compound.

A perfect joint sleeve compound would possess the following properties—

1. Be a thin liquid at 115° C. This property is to enable it to flow freely into all the interstices within the sleeve at a temperature which will not damage the cable or joint insulation.

2. Be a homogeneous solid at 50° C. This property is to prevent it from penetrating into the cable at working temperatures, and to ensure a regular distribution of stress. The temperature of 50° C. has been arbitrarily fixed as the maximum temperature reached by the compound; but in so fixing it, because definite

information on the point is not in my possession, I have taken the maximum temperatures of the conductors as 65° C. and assumed that a not less drop than 15° C. occurs between the conductors and the insulation with which the compound is in contact.

3. Be of tenacity such that it would not develop fissures or holes in the body of the compound from strains set up in itself by cooling. This property is an extension of the requirement postulated in 2.

4. Be of elasticity such that it would not develop cracks when subjected to vibration. This property is to enable it to withstand the shocks to which it is liable in the situations in which joints are placed.

5. Possess constant volume between temperatures of 5° and 50° C. This property is to enable it to keep within and to fill the sleeve at all working temperatures. No doubt, this is impossible exactly to attain, but, other things equal, that compound having the lowest coefficient of expansion with variation of temperature is the best.

6. Not decompose at 150° C. This property is to enable it to withstand the slight overheating such as is practically unavoidable during preparation on the site.

7. Have a specific inductive capacity similar to that of the impregnated paper used in cable manufacture. This property is to ensure that the distribution of stress in the joint insulation is not markedly different from the distribution in the cable.

8. Possess ample resistance to breakdown by electrostatic stress. This property is to enable it to withstand the dielectric stresses (they are much lower than the stresses in the main insulation) which are met with

in its situation within the sleeve, but not adjacent to the conductors.

9. Coalesce with the cable insulation, and adhere to lead. This property is to ensure that there is no discontinuity in the insulation, and therefore no liability to sudden change of stress or to electrostatic discharge.

10. Neither deteriorate with age, nor attack any of the materials comprising the joint. This property is a self-evident requirement.

A property which is not essential, but which is advisable in order that accidental damage to the sleeve does not permit water to penetrate to the main insulation, is that the compound should be non-hygroscopic.

Summary.

And what is the sum total of all my remarks on insulation ? The sum total is this: Joints for working pressures up to 12,000 volts should be insulated with oil impregnated cotton tape, and the sleeve filled with a compound possessing so nearly as possible the properties already outlined ; and joints for higher pressures should be insulated with impregnated paper tubes assembled under oil, and the sleeve filled with oil similar to that used in the impregnation of the cable.

CHAPTER V

THE SLEEVE

As has been said earlier in this book, the joint sleeve should be of pressed lead. For diameters up to six inches, lead pipe with a $\frac{3}{16}$ in. wall is readily obtainable and is sufficiently stiff for most purposes. Larger diameter sleeves, and sleeves for special purposes, may be made of sheet lead. In making such sleeves, the needful lengthwise joint is best made with a welt as illustrated in Fig. 16.

In general, in preparing the sleeve for the joint, one of two forms may be given to it. One form is economical of labour and ensures concentricity of cable and sleeve, but is wasteful of material and apt to allow of air bubbles collecting at the top of the sleeve. The second form calls for greater skill on the jointer's part, saves material, and is technically sound.

Types of Sleeve.

The one form consists in having a simple cylindrical sleeve, in fixing at each end a centring ring of lead, having an outside diameter similar to that of the inside of the sleeve and shaped as the frustrum of a cone, on to the cable sheath; in beating the sleeve on to the ring; and in plumbing over the junctions of sleeve ring, and sheath, all as shown in Fig. 17.

The other form consists in beating the ends of the sleeve so that they taper from the filling holes, of which there should be two, shortly to be mentioned, to the sheath. This is illustrated in Fig. 18.

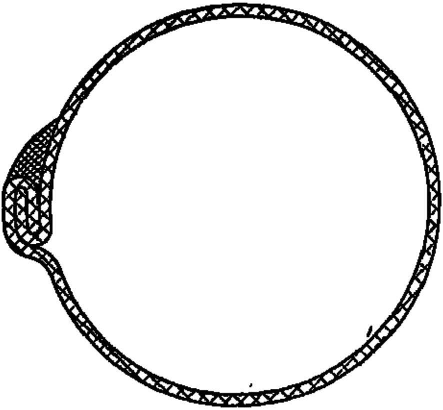


Fig. 16. Welted Seam

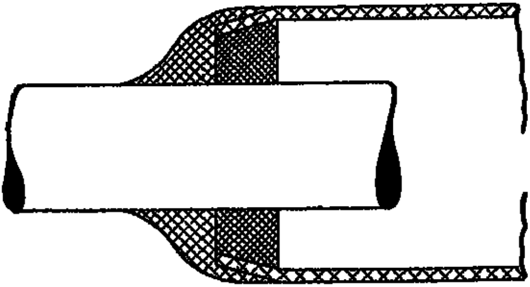


Fig. 17. Lead Ring and Sleeve End

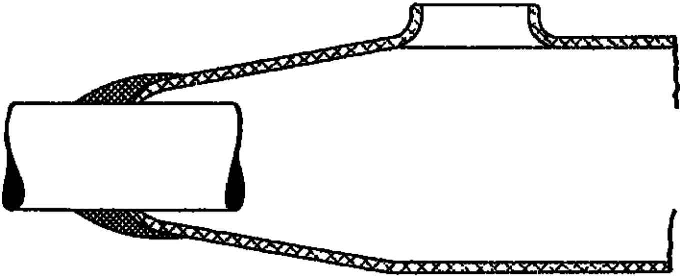


Fig. 18. Tapered Sleeve End

From what has already been said, it will be known which form I prefer. But, in order that the advantages of the second form should plainly appear, I will outline them: The minimum amount of plumbing metal is required to ensure a sound wipe at the junction of sleeve and sheath; compound is economized, not to a large extent, it is true, but—every little helps; and, the outstanding advantage, air pockets are eliminated, for whatever air might otherwise collect at the end of the sleeve during the pouring of the filling compound, rises by gravity to the filling holes, while any air that may collect between the holes is driven out by pouring in at one hole only.

The method of preparing the sleeve which consists in beating down each end so that it forms a blunt nose, is one possessing the disadvantages of both the forms previously noted with the advantages of neither, and has no excuse other than caprice for its adoption.

Filling Holes.

Filling holes are sometimes made by slitting the sleeve and turning up the edges, or by making a V cut and turning up the tongue, which edges or tongue are beaten back into place after the compound has been poured; but such methods are dangerous inasmuch as there is great risk, often materializing into fact, that metal will enter the sleeve during the soldering of the slits or cuts. Therefore, such methods are not sound. Filling holes should be made by, first, boring a small hole through the sleeve wall at the point where the centre of the filling hole is to be, and then beating up the lead so that the finished holes have lips rising like craters from the top of the sleeve. The height of a crater will depend upon the size of the hole, but with a 2 in. diameter hole, a crater wall ¾ in. high can be obtained, and such height is proper for the purpose. This purpose is to permit of an air space being left above the surface of the compound, so that, when the caps are being plumbed, compound will not ooze from the holes. Further, as in a sleeve completely full of compound, the compound, when the joint becomes warm and expansion occurs, penetrates into the cable, whence, owing to friction, it does not readily emerge, and as, therefore, on cooling, voids arise within the sleeve, or it becomes deformed, so a slight, but additional advantage of having the air space within the

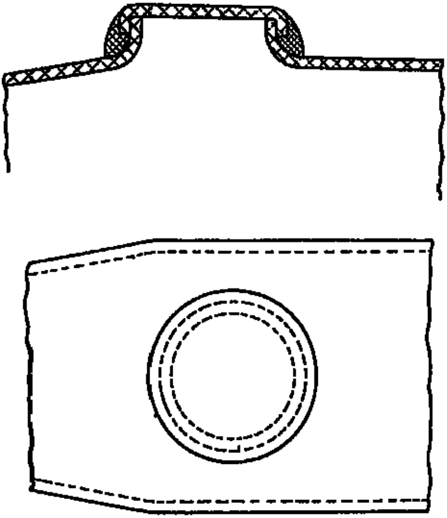


Fig. 19. Filling Hole and Cap

crater is that room is provided for a little expansion of the compound. The holes and caps are shown in Fig. 19.

And so, the fully developed sleeve is shaped as in Fig. 20. But that is only for cables having working pressures up to 12,000 volts, because, for higher pressures, means have to be provided for large variations in the volume of compound within the sleeve.

Before tackling the larger matter, mention must be made of the difficulty of beating heavy sleeves, and of those occasions when it happens that room for jointing is so restricted, as, for instance, in improperly designed pits, that the sleeve cannot be slipped over the cable before the conductors are jointed.

Beating Heavy Sleeves.

The beating down of one end of a heavy sleeve after insulating is complete, is a backaching task which the lazy and the inexpert may well seek to evade. So, such workmen may consider as permissible the cutting through of the sleeve at any convenient point, the beating down of the ends, which have to be plumbed to the sheath, before slipping the divided sleeve over the cable, and the joining of the two pieces by an encircling collar which is plumbed in place before the ends are plumbed to the sheath. The objections to so doing are that additional plumbs are needed, a matter always to be avoided, and that a longer time is taken to complete the joint. The backaching task may be diminished, and risk of damage to cable and joint may be avoided by resting the sleeve, during beating of the end, on roller bearings suitably placed. One such bearing is illustrated in Fig. 21.

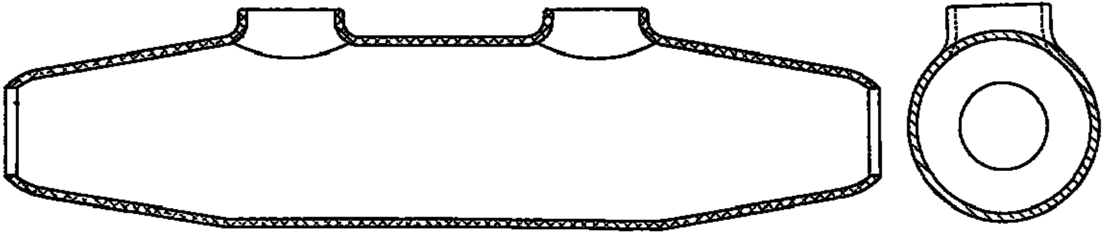


FIG. 20. TAPERED SLEEVE

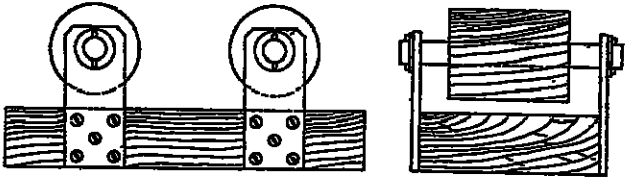


FIG. 21. ROLLER BEARING FOR USE WITH HEAVY SLEEVES

Seamed Sleeves.

On occasions when a whole sleeve cannot be slipped over one of the cable ends, the sleeve may be cut across into similar halves, each half, after treatment, as indicated in Fig. 22, slipped over a cable end, the conductors jointed and insulated, the halves brought together and plumbed in the middle, and then their ends plumbed to the sheaths. Or, the sleeve may be slit lengthwise, opened, put around the joint, closed, and the remaining seam plumbed. In preparing a sleeve for these operations, the two edges of the seam may be halved for overlapping, as shown in Fig. 23a, the overlap being not less than ⅜ in. That is the better way, but as occasions to use split sleeves are rare, jointers have, as a rule, insufficient practice at this work to become expert. So, a permissible seam joint is made by scarfing, as shown in Fig. 23b, the overlap in this case also being not less than ⅜ in. In each case, the overlapping part should point downward. Never should a seam just butt, and never should the plumbing be done when the seam is at the top of the sleeve, for in both those ways, metal, while plumbing, will penetrate the seam, and either solidify as projections on the inside, like stalactites in a cave, and appear as the serrated skyline of a distant range of mountains; or fall as blobs on to the insulation, neither of which happenings are desirable.

Provision of Oil Reservoir.

The need to provide a reservoir in joints for pressures exceeding 12,000 volts necessitates modification of the sleeve already evolved, when used for such

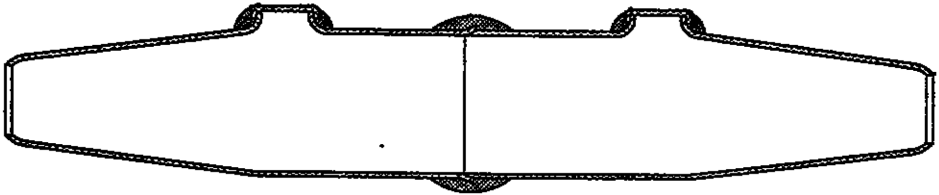


FIG. 22. DIVIDED SLEEVE

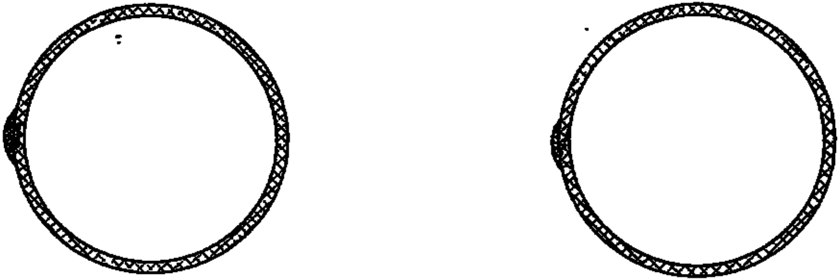


FIG. 23 (*a*)

FIG. 23 (*b*)

SLEEVE SEAMS

joints. In the first place, as the size and functions of the sleeve are increased, it should have not less than a ¼-in. wall, in order that it may withstand the mechanical forces to which it may be subjected. Usually, the reservoir has taken the form of one or more domic projections from the top of the sleeve, but as such projections involve special work and much expense, so a suitable construction using only standard material would be advantageous. One such construction consists in retaining the form of sleeve already developed and connecting the filling holes by an inverted U-shaped lead pipe having a small filling hole at the top, all as in Fig. 25. When that construction is used, the U pipe is plumbed in position after the sleeve has been filled with oil. Thereafter, further oil is added until the desired level is reached, and the small cap is plumbed to the pipe.

That method of providing a reservoir takes up much room, so, when room is wanting, or when a large reservoir is needed, the construction may be adopted wherein, still retaining the same general form of sleeve, one or more vent holes are cut in the bottom of the sleeve and the sleeve enclosed in an outer sleeve plumbed in its turn to the cable sheath and filled with oil to the desired level. This construction is shown in Fig. 24.

In making a joint with this double sleeve, the vent hole is closed until after the inner sleeve has been filled with oil, cooled, and the filling holes capped. Then, the outer sleeve is drawn into position, the ends plumbed, the requisite amount of oil poured, and the cap secured. Thereafter, so long as there is oil in the outer sleeve, only oil can enter the sleeve proper,

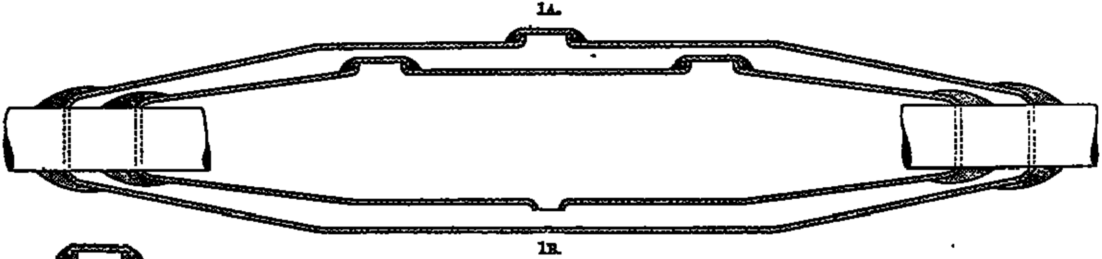
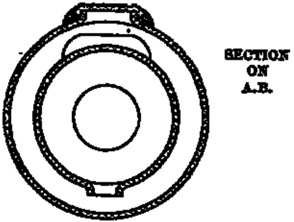


Fig. 24. Double Sleeve



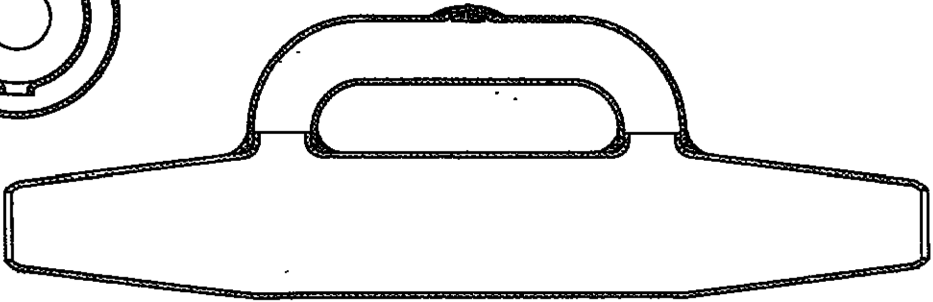


Fig. 25. U-Expansion Chamber and Sleeve

is kept filled by the pressure of air above the oil
outer sleeve.

modification of the preceding is that wherein the
voir is contracted to an annular chamber surround-
e middle length of the sleeve. This form of reser-
ossesses the advantages over its archetype in that
be plumbed in position before the sleeve is slipped
the cable, and that the stopping of the vent hole
g the filling of the inner sleeve is obviated, and
uch time is saved. Still more time can be saved
rranging the two sleeves eccentrically, as in Fig.
nd, what is more, any desired ratio between the
ne of air and the volume of oil in the reservoir
e secured at one filling by suitably proportioning
eccentricity.

utions for Extra High Pressures.

r joints of higher working pressures than 20,000
, a good case can be made out for maintaining a
pressure within the joint and cable. But, to be
ether effective, the pressure should be applied
cable and joint are at or over maximum working
erature. A modicum of benefit, however, may be
ned by forcing air into the reservoir, or oil into
leeve at the time of making the joint.

hen it is desired to maintain a fluid pressure within
leeve, a non-return valve may, after the oil has
poured, be fixed to the hole in the reservoir top,
ir forced in until any desired pressure is reached.
he air valve may be omitted, and oil forced into
sleeve through a valve fixed in one of the filling
. No rule can be laid down for the size of the
voir, or the pressure to be maintained within it,

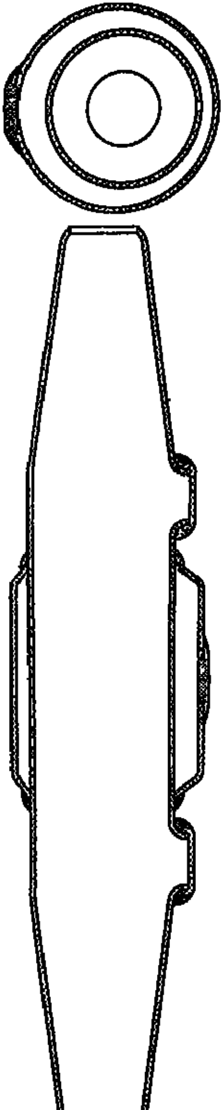


FIG. 26. ECCENTRIC CONTRACTED DOUBLE SLEEVE

for both depend on many factors, among which are the coefficient of expansion of the oil used, the percentage of air in the cable, and its length.

Because holes in the sleeve upset the even distribution of stress in the insulation, and because the surface of the oil within the craters of the filling holes is in contact with air through which electrostatic discharge may take place, a refinement would be that sleeves for very high pressures, say of 30,000 volts and over, should have their filling holes covered by a screen of wire gauze which is always below the oil surface, and electrically connected to the sleeve. An arrangement is indicated in Fig. 27.

Dimensions of the Sleeve.

The dimensions of the sleeve depend upon the size of the conductor and upon the voltage of the cable. The inside diameter should be such that, in the smaller sizes of sleeves, there is a ¼ in. clearance, more or less, between the belting of the bunched insulated conductors and the sleeve wall. This clearance is in order to permit the filling compound to flow freely. The length should be such that easy bends are possible in the cores from the crutches to the conductor joints, that one inch of untouched cable insulation per 8,000 volts of working pressure exists between the end of the sheath and the crutch at each end of the joint, and that the sheaths can be slightly belled just within the sleeve.

Notes on Plumbing.

Some mention must now be made of plumbing methods: Foremost, it is essential that the plumbing metal be clean and rightly proportioned. Both can be secured by preparing it in the way already described for solder, except that the weights of lead and tin should be reversed.

The "soil," "smudge," or "tarnish" which is used to prevent metal from adhering where it is not wanted may be obtained in packets all ready for mixing with water; but as it may happen that a packet cannot be obtained, and as, in any case, a craftsman prefers to know what he is using, and so will make it for himself, so brief directions for the making of soil, smudge, or tarnish, here follow. Ingredients: size, lampblack, water. Dissolve the size in hot water so that a thick paste is formed. Pour some of the paste on to a smooth stone slab, and add the lampblack gradually, thoroughly mixing all the while. When all is mixed,

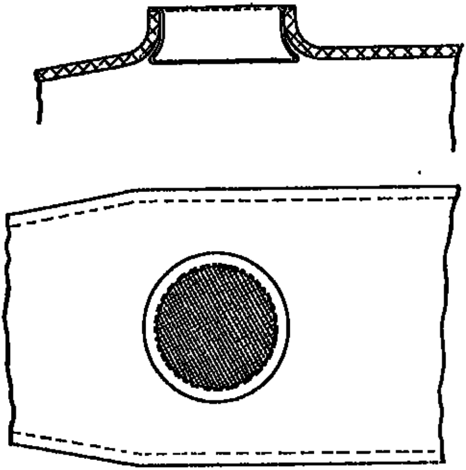


FIG. 27. SCREENED FILLING HOLE

add slowly to the remainder of the dissolved size, stirring well continually. Then, let the mixture be kept hot, but not boiling, for a quarter of an hour, and it is ready for use. Such a mixture will keep, and may be thinned with water as necessary. The snags in this as in many other processes, are to be learnt by practice rather than by fuller description.

Plumbing may be divided into three main operations: (1) The tinning of the parts to be joined; (2) The forming of the joint; (3) The wiping. A highly-skilled man will perform all three operations almost simultaneously by pouring metal over the joint, using only ladle and wiper. Or, a process made possible by the modern blowlamp, he will first heat the parts with the lamp, then tin them with a stick of metal, the lamp playing all the time, and leave enough metal adhering so that, with lamp and wiper, the joint is finished. A less skilled man will tin the parts with solder and lamp; then pour metal over, gathering it in a wiper, and then form and finish the wipe. Of course, the metal should be at the right temperature. This is indicated by the turning of a piece of dry white paper thrust into the liquid metal to a dark brown. Too hot a metal will burn holes in the lead sheath or sleeve, or in both, and too cold a metal will not properly join them.

Protecting the Joint.

The functions of the box enclosing the sleeve are to provide mechanical protection comparable with the protection afforded to the cable by its armour, and electrical connection between the cable armour on each side of the joint. If these functions can be suitably met by one thing, then that thing, provided, of

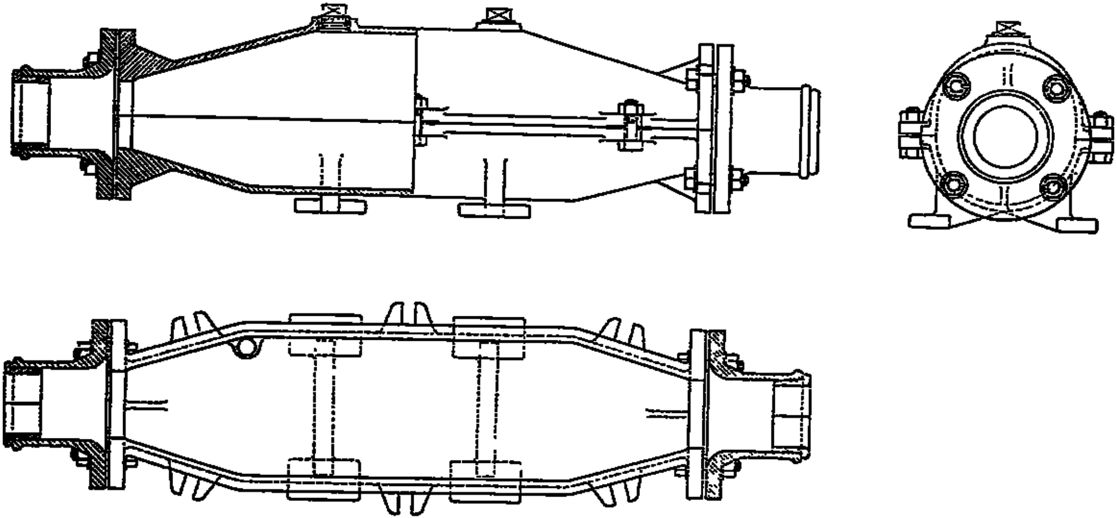


FIG. 28. CAST-IRON JOINT BOX

course, that its cost be not out of proportion to its usefulness, is the one to be adopted. The thing which efficiently meets all needs is a cast-iron box. It is needless to go into the detail of the design of this: sufficient it will be to state that the chief requirements are that it shall enclose the sleeve and the whole of those parts of the cable which have been disturbed during the jointing operations; that it shall securely clamp the armour; and that it shall have means for bonding the sleeve to the box so that the two are at the same potential. Also, it should allow of the sleeve being supported so that all the weight of the joint does not come on to the cable at the ends of the joint; allow a clearance of not less than ¾ in. between sleeve and box in order that compound may readily flow all round; and, for filling purposes, there should be holes fitted with plugs in the top of the box. A design which fulfils all requirements is illustrated in Fig. 28.

CHAPTER VI

JOINTING A THREE CORE CABLE

To complete the programme previously laid down, I have to describe the making of a complete joint. So, here is a description of the operations of jointing a three core paper insulated lead sheathed single wire armoured cable, using ferrules, cotton tape, compound sleeve, and box, all as shown in Fig. 29.

Before starting to joint, the two cables to be jointed will overlap from one to three feet, according to the class of cable and to the way it has been handled.

Preparing the Ends.

To joint, the operations and the order of their performance are as follows—

Cut each cable approximately midway between the overlapping ends so that the cables overlap an inch or two. Slip over each end an armour clamp. Remove only so much of the outer serving as will permit wholly undisturbed cable to lie well within the armour clamp end in the finished joint. Nick the armour wires with a three-corner file and break off each end at a point such that they are of the correct length to fit in the armour clamp when that is to be fixed, and bind with wire to keep them in place. Remove the inner serving, or waterproofing, and clean the sheath. Over one cable, which has been covered with clean dry paper, slip the sleeve which previously has had one end beaten to the required shape and the filling holes

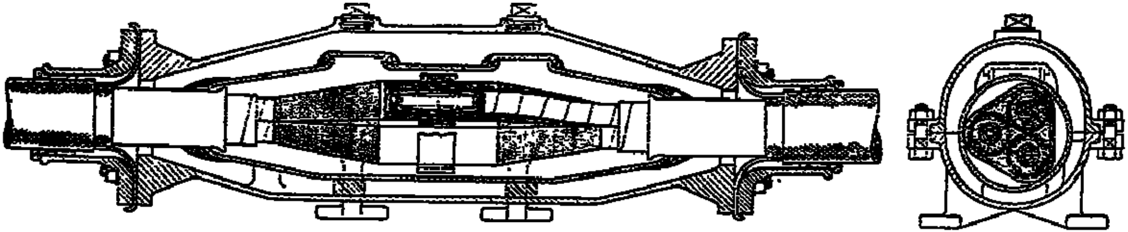


FIG. 29. COMPLETE TAPE-INSULATED JOINT

formed. With hack knife and hammer, cut each sheath all round through two-thirds of its thickness at the place where the crutch will occur in the finished joint; lengthwise from the nicked sheath to the cable end, make a slanting cut so as not to damage the paper underneath, and tear off the lead: in this way, a slight bell will be given to the sheath remaining on the cable. Remove the paper belt around the wormed cores, taking care not to damage the core papers: the ten innermost layers of belt paper should be torn off. Round the three cores and adjacent to the sheath, bind five layers of impregnated tape one inch wide and make off, as should always be done in like case, with two half hitches: this binding, in addition to serving as a marker, forms a temporary semi-rigid crutch and so prevents undue movement of the cores at, and thereby weakening of, the permanent crutch. If, as will often happen, the cores to be joined together do not lie in line, adjust them until they do by slightly bending them from the crutch; and bend the ends inwards so that the parts to enter the ferrules lie parallel to the lengthwise axis of the joint. The latter operation is expedited by inserting a three-pronged spreader between the cores at the point where the bend is required, and then to squeeze the ends together. Bind each core with dry cotton (threads drawn from impregnated tape serve well) at a point half an inch beyond where the ferrule end will ultimately be, and so prevent unwinding of the paper. Remove the insulation from each conductor from the end to a quarter of an inch beyond what will be the position of the ferrule end. With impregnated tape, bind two layers over the paper of each core from where it has been cut to the crutch: impregnated tape is used in order to prevent absorption of the cable impregnation.

Soldering the Conductors.

These preparations having been made, the bared part of each conductor is to be sweated solid with solder, and such part cut off as will permit the ends to butt in the centre of the joint. The ferrules are slipped over the three conductors of one cable, both cables lifted until the other conductors enter the ferrules, and the whole placed in position. (Exceptionally, when room is so restricted that an easy bend in the cable is impossible, it is permissible to bare the conductors on one side of the joint centre to the full length of a ferrule. In such case, a longer taping is necessary and so a longer sleeve.) The conductors should now butt in the centres of their ferrules, and the cores bulge at their central parts just enough to enable taping to be carried out. Pour over the ferrules, each in turn, hot (the correct temperature may be gauged as in the case of plumbing metal) molten solder until the ferrule and contained conductors are thoroughly hot and solder flows freely through the joint, then pour in cooler and cooler metal until the whole is about to solidify. A deft movement with a clean, smooth, and dry rag is now needed to wipe the ferrule and conductor clean, and to fill the slot with solder.

Insulation.

To insulate, remove $\frac{1}{8}$ in. of paper from each core adjacent to the ferrule ends, and take off the tape binding round each core. Fill with impregnated tape the gap between one end of a ferrule and the paper of the core to the outside diameter of the ferrule, and, with the same length of tape, wrap tightly and with a half lap the core up to one temporary crutch, back, fill the other gap, wrap the ferrule till the taping over it is at the level of the outside of the core paper, and continue to the other temporary crutch. Then return with the tape to a point beyond the far side of the ferrule such that when taping is complete the proper thickness will have been applied, and back again to a similar point on the other side of the ferrule. Now, shortening the taped length by $\frac{1}{10}$ in. as each layer is completed, tape and tape and tape until the required insulation has been wrapped. Similarly with the other cores. When all have been taped, the central part of each core will be cylindrical, and from the cylinder ends the insulation will taper neatly almost to the crutch. Then, in the centre of the cylindrical parts, that is, midway between the crutches, bind each core separately with 1½ in. impregnated tape until each is encircled by a band ⅛ in. in radial thickness; and then, over the bands, after tape wads have been placed in the four crevices, bind the whole tightly together with tape until there is a belt of the proper thickness.

Remove the correct length of lead sheath from the cable at each end of the joint, bell the sheath with the belling tool, bind the exposed paper belt with five layers of impregnated tape, and remove the tape which has been holding the cores together to form the temporary crutch.

Slip the sleeve over the now insulated joint, beat the ends down until they grip the sheath, and plumb. In the plumb, it is not necessary to have much metal to make a sound job: about a pound and a half of metal at each is enough for a two inch diameter cable.

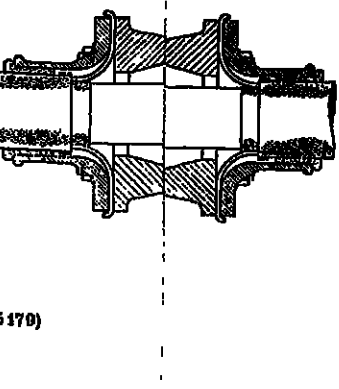
Filling with Compound.

While the sleeve is still hot from the plumbing, pour in compound at 120° C., taking care to pour in a steady stream (to avoid entrapping air) into one only of the filling holes until the sleeve is one-third full of compound. Wait five minutes in order to allow the compound to fill whatever interstices there may be in the joint. Pour in hot compound until the sleeve is two-thirds full. Wait another five minutes. Fill the sleeve with compound to the level of the top of the craters. As the compound shrinks, top up with compound, always at a temperature of 120° C.: as the joint gets cooler and cooler, less and less compound is needed at each topping. Towards the close of the topping operations, pour the compound only to a level $\frac{1}{8}$ in. below the top of the craters. When the joint is cold, place the caps over the craters and plumb to the sleeve. This last operation must be done quickly, else the compound will expand sufficiently to ooze through and so to spoil the plumb.

While the joint is cooling, the armour wires may be turned into position, the bottom half of the iron box fixed, and the bond bolted to the box and soldered to the sleeve. After the caps are fixed, the top half of the box is put in place, the armour clamps fixed and tightened up, and the box filled with compound. Next day, the iron box is topped up.

Time Occupied in Making a Joint.

A skilful jointer will make such a joint in nine hours,



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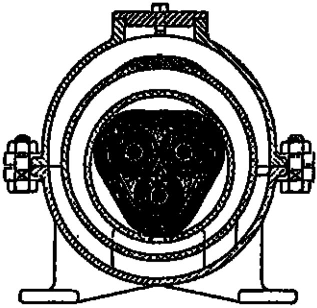

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about three of which are taken up by the cooling of the compound; but this time is not unoccupied, as, during it, as before said, the box and armour clamps are partly fixed, and, further, the sleeve for the next day's work is prepared.

That fulfils my contract. But, as a work of supererogation, the outstanding differences between the procedures of making a taped joint as just described and a slip-on-tube joint as shown in Fig. 30, are noted below.

Points on Making a Slip-on-Tube Joint.

Before sweating the conductors, slip the tubes over their respective cores so that they lie between the crutch and the bare coppers. Lap the jointed conductor, after sweating, with impregnated fine cotton tape until the core from crutch to crutch is one smooth cylinder. Then, lap the core, half at a time, with similar tape to a radial thickness of ·05 in. along the length upon which the tube will bed and an inch over at each end. Immerse the whole of the joint so prepared in a trough of oil: on wet days, the oil should be at a temperature of 115° C., and should be kept at that temperature so long as bubbles rise to the surface; but during fine weather, the oil may be at a temperature just high enough to permit it to run freely, say, it should be as viscid as cream. When all is as ready as all should be, slowly move each tube in turn from its temporary position to a similar position at the other end of the joint. Then, back to its first position. And then to its central and final place. The oil should then be allowed to cool to a temperature such that it will not readily run, and the trough removed from the cable. After wrapping the anchoring, banding, and belting tapes in place, slide the sleeve into position, beat down the ends and plumb them to the sheaths. Pour oil at 120° C. into the central hole until clear oil flows from the other holes. Fix a large funnel, fitted with fine wire screen and cock, to one of the holes in the inner sleeve. Fill the funnel with oil and, when all is still and all air has been removed, turn the cock and allow oil to flow from the other hole until perfectly clear oil only comes out. Place all caps in position and plumb them, taking care to leave open the pinhole in the reservoir cap. Fix the iron box and fill with compound to the level of the reservoir top. Next day, plug the pinhole with lead wire, seal with the soldering iron, top the box up, bolt the lid in place, and the joint is complete.

Conclusion.

In bringing this book to a close, may I say that engineering is not to be divorced from culture: man lives not by machinery alone, but by the exercise of every faculty of his being. It is when engineers are too purely technicians, too insufficiently human, that they exercise too little influence on the general affairs of mankind: Engineers influence mankind in so far as they themselves are influenced by Art.

APPENDIX

Table 1. Jointer's Kit.

NOTE. The composition of a jointer's kit will depend upon the work that has to be done. So, it should not be assumed that every tool listed below should find a place in every kit.

The following table contains a brief description of the tools and the number required by a jointer who has to do a varied class of work. Those items preceded by a number within brackets are enlarged upon in the subsequent notes.

(1)	Tool box, 30 in. × 18 in. × 12 in. deep, with shelf	2
	Cutting pliers. English, 8 in., 6 in., and 4 in., each	1
	End cutters, 6 in.	1
	Steel wire nippers, double lever, 8 in.	1
	Gas pliers, 8 in. and 6 in., each	1
	Tinman's shears, 10 in.	1
	Scissors, 8 in.	1
	Hack saw frame	1
	,, ,, blades, 12 in.	12
	Tenon saw, 10 in.	1
	Hand saw, 28 in.	1
	Plumber's knife	1
	Pocket knife, single blade	1
	Shoemaker's knife	1
	Hack knife	1
	Oil stone, 8 in.	1
	Half round file, 12 in. and 8 in., each	1
	Flat file, 12 in. and 8 in., each	1
	Round file, 12 in. and 8 in., each	1
	Three corner file, 12 in. and 8 in., each	1

	Rasp, 12 in. and 8 in., each	1
	File card on wood, 6 in. × 3 in.	1
	Carpenter's hammer, 1 lb.	1
	Fitter's hammer, 2 lb.	1
	Cold chisel, 18 in. × 1 in., and 8 in. × 1 in., each	1
	Screwdriver, 18 in. and 9 in., each	1
	Bradawl, ⅛ in.	1
	Gimlet, ¼ in.	1
	Plumber's gouge, or lead borer	1
	Carpenter's Chisel, 1⅛ in.	1
	,, gouge, 1 in.	1
	,, ratchet brace	1
	,, Bit, ⅜ in., ½ in., ⅝ in., ¾ in., 1 in., and 1¼ in., each	1
	Twist drill with square shank, $\frac{5}{16}$ in., $\frac{7}{16}$ in., and $\frac{9}{16}$ in., each	1
	Two fold, two foot steel rule, 16ths and 10ths	1
	Spirit level, 10 in.	1
	Soldering iron, 1½ lb.	1
	Melting pot, 7 in. and 6 in., each	1
	Hook for melting pot	1
	Ladle, 4 in. and 3 in., each	1
	Paraffin blow lamp, 1 pint	2
(2)	Oil furnace	1
(3)	Wipers, 3 in. × 3 in., 4 in. × 6 in., 6 in. × 9 in., each	1
	Lead beater, medium size	1
	Turn pin, 2 in. and 4 in., each	1
	Bent pin, or plumber's tommy	1
	Plumber's straight hand dummy	1
	Plumber's shavehook	1
	Smudgebox and brush	1
	Tinbox for resin	1
	,, ,, tallow	1
	,, ,, resin and palm oil paste	1
	Oil can with screw stopper, 1 quart and 2 gallon, each	1
	Funnel, outlet ¼ in. and ¾ in., each	1
	Iron saucepan with lid, 8 in.	2

	Wire cage to fit within saucepan	2
(4)	Tape winder	1
	G.I. bucket with lip and lid	2
(5)	Firedevil	2
	Clyburn spanner, 12 in. and 8 in., each	1
	Callipers, outside, 6 in.	1
	Bricklayer's trowel, 6 in.	1
	Mirror, 4 in.	1
	Centre punch	1
	Bear punch for ¼ in., $\frac{5}{16}$ in., and ⅜ in. holes	1
(6)	Thermometer, 0° to 200° C.	1
(7)	Rubber mat, 18 in. × 12 in. × ¼ in.	3
	„ gloves, pair	1
	„ boots, „	1
	Measuring tape, 100 ft.	1
(8)	Belling tool	1
	Copper strips, 3 in. × 1 in. × 20 S.W.G.	100
	Wedges, hard wood, 6 in. × 1 in. × 1 in.	4
	Spreaders, hard wood, three pronged, ¾ in. and 1¼ in. prongs, each	2
(9)	Tent frame	2
	Tarpaulin, 16 ft. × 16 ft.	2
	Tar boiler, 25 gal.	1
(10)	Testing set	1
(11)	Mandrel, hardwood	1
	Special tools for special purposes.	

NOTES

1. *Tool box:* Should be well made and bound with iron, so that it will withstand rough usage. Two relatively small boxes as listed, are better than one large box, for they are more easily handled and their contents are more get-at-able. It is fitting that the finer tools should be kept in one box, and the remainder, together with the solder, plumbing metal, tape, rags, and odds and ends which a jointer carries about, in the other box.

2. *Oil Furnace:* Only occasionally needed, and not recommended.

3. *Wipers:* The sizes listed are given as examples only: other and larger sizes are often used. They are made by folding moleskin until from 8 to 16 layers exactly overlap, and the

finishing edge sewn through. The number of layers may be reduced by inserting brown paper between the layers, but this reduces the flexibility of the complete wiper. The sewn wiper should be soaked in tallow, and each time before using, it should be rubbed on its working surface with tallow.

4. *Tape Winder:* A simple machine for winding tape on to spools before final boiling. It saves much time.

5. *Firedevil:* A useful form is made from 8 s.w.g.-sheet iron rolled into cylindrical form and rivetted. It is divided into two equal parts by a grate of ½ in. square bars; a 6 in. semicircular piece is cut from the bottom of the cylinder; and the top half is pierced with 1 in. holes at 5 in. intervals. Such a devil burns coke well, and what is more to the point, it heats well.

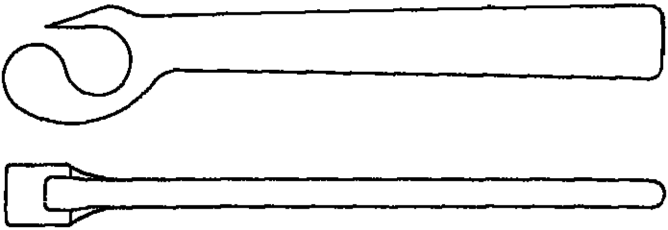

FIG. 31. BELLING TOOL

6. *Thermometer:* Should be steel cased and packed in a wooden tube.

7. *Rubber Mat and Gloves:* Not required on the usual run of construction work, but handy in emergency.

8. *Belling Tool:* As this is not commonly known to jointers, at any rate, it is not commonly used by them, a sketch of one is given in Fig. 31.

9. *Tent Frame:* Almost as many varieties of frame exist as there are engineers who design them. The one I prefer, as it is very flexible, is a wooden collapsible braced frame which, when erected, is of inverted V shape, the apex being separated by 2 ft. long timbers, and having each side 8 ft. long by 6 ft. high.

10. *Testing Set:* A galvanometer giving a visible deflection when in series with five megohms and a hundred volt battery. Or, a megger.

11. *Mandrel:* Diameter similar to that of inside of sleeve, and 9 in. long.

TABLE II—DIMENSIONS OF LAPPED JOINTS

SEE FIG. 3, PAGE 22

Cross-sectional Area of Conductor: sq. in.	Number of Strands in Conductor	Distance between Butts in Outside Layer: in.	Size of Binding Wire: S.W.G.	Overall	
				Diameter	Length
				in.	in.
·06	19	3	20	·4	4
·1	19	3	20	·5	4
·15	37	4	20	·59	5
·2	37	4	18	·69	5
·25	37	4	18	·76	5
·3	37	4	18	·83	5
·4	61	5	16	·98	6
·5	61	5	16	1·07	6

TABLE III—DIMENSIONS OF DRAWN COPPER FERRULES

SEE FIG. 4, PAGE 24

Cross-sectional Area of Conductor: sq. in.	Assumed Maximum Current:	Diameter			Length:	Width of Slot:
		Inside	Outside			
	amps.	mils.	mils.	16th in.	in.	32nd in.
·06	150	320	420	7	3	3
·1	200	415	550	9	3	3
·15	250	504	670	11	3·25	4
·2	300	581	770	13	3·25	5
·25	350	651	860	14	3·5	6
·3	400	721	950	16	3·5	6
·4	460	837	1100	18	3·5	7
·5	520	927	1220	20	3·5	8

TABLE IV—DIMENSIONS OF VERNIER BRAID JOINTS

Cross-sectional Area of Conductor: sq. in.	Weight of each Braid per foot: oz.	Number of Braids			Length of each Braid			Size of Binding Wire:	Overall of Joint		Authority
		Inner Layer	Middle Layer	Outer Layer	Inner Layer: in.	Middle Layer: in.	Outer Layer: in.	S.W.G.	Diameter: in.	Length: in.	
					FIG. 5A p. 28						
·06	·85	–	–	3	–	–	2·75	20	·56	3·25	The Inventor
·1	1·75	–	–	3	–	–	3	20	·72	3·5	” ”
·15	2·7	–	–	3	–	–	3	20	·82	3·5	” ”
·2	4·4	–	–	3	–	–	3·5	18	·95	4	” ”
·25	6·9	–	–	3	–	–	3·5	18	1·1	4	” ”
·2*	2·7	–	–	4	–	–	3·5	18	·94	4	The Author
·25*	2·7	–	–	5	–	–	3·5	18	1·02	4	” ”
					FIG. 5B p. 28						
·2	1·75	2	4	4	1	2·5	4	18	·92	4·5	The Inventor
·25	2·7	2	3	4	1	2·5	4	18	1·05	4·5	” ”
·2	1·75	3	–	3	2·5	–	4·5	18	·92	5	The Author
·25	1·75	3	–	5	2·5	–	4·5	18	·99	5	” ”
·3	2·7	3	–	4	3	–	5	18	1·08	5·5	” ”
·4	1·75	3	4	5	2·5	4·5	6·5	16	1·22	7	” ”
·5	2·7	3	4	5	2·5	4·5	6·5	16	1·33	7	” ”

* Generally suitable.

NOTE. In venturing to vary from the Inventor, as I do in two cases and their alternatives, I do so in order either to reduce the number of sizes of braid needed to cope with all the conductors commonly used, or to simplify the work by making unnecessary the disturbance of the central nineteen strands of any conductor.

TABLE V—DIMENSIONS OF SLIP-ON-PAPER TUBES TO BE ASSEMBLED UNDER OIL

SEE FIG. 10, PAGE 40

Voltage of Cable:	Radial Thickness of Paper round Conductor in Cable: in.	Thickness of Tube Wall: in.	Length of Tube	
			Overall: in.	Parallel part: in.
20,000	·2	·3	7·5	6·5
33,000	·25	·38	9·5	8

TABLE VI—DIMENSIONS OF IMPREGNATED COTTON TAPE INSULATION

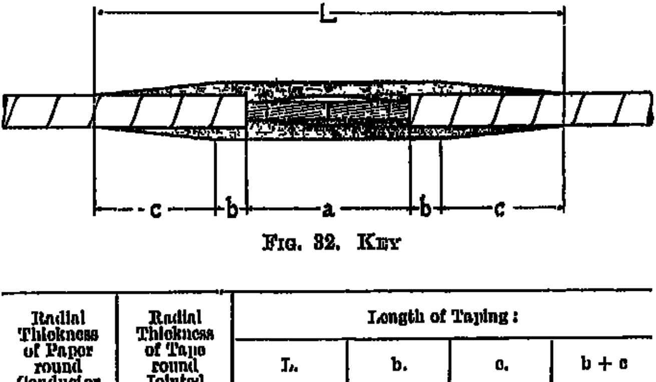

FIG. 32. KEY

Radial Thickness of Paper round Conductor in Cable: in.	Radial Thickness of Tape round Jointed Conductor: in.	Length of Taping:			
		L. * in.	b. in.	c. in.	b + c in.
·05	·1	6½	¼	1	1¼
·07	·14	7½	¼	1½	1¾
·1	·2	9	½	2	2½
·15	·3	11½	¾	3	3¾

* 'a' assumed to be 4″

TABLE VII—DIMENSIONS OF FERRULE AND TAPE JOINTS

Fig. 29, Page 72

Cross-sectional Area of Conductor:	Outer Diameter of Ferrule:	Diameter over Taped Ferrule:	Diameter over Banded and Taped Ferrule:	Diameter over Bunched, Banded, and Taped Ferrules:	Diameter over Belted, Bunched, Banded, and Taped Ferrules:	Inside Diameter of Sleeve		Distance between Crutches:	Distance between Sheaths:	Length of Sleeve:
						Calc.	Actual *			
sq. in.	16th in.	16th in.	16th in.	16th in.	16th in.	16th in.	in.	in.	in.	in.
·06	7	10	14	30	32	40	2½	11	11½	13
·1	9	12	16	35	37	45	3	12	12½	14
·15	11	14	18	39	41	49	3	13	13½	15
·2	13	16	20	43	45	53	3½	14	14½	16
·25	14	17	21	46	48	56	3½	15	15½	17
·3	16	19	23	50	52	60	4	16	16½	18
·4	18	21	25	54	56	64	4	17	17½	19
·5	20	23	27	59	61	69	4½	18	18½	20

660 volts = Working Pressure of Cable.
Crutch to Sheath = ¼ in.

Radial thickness of Tape round Ferrule = 3/32 in.
Radial thickness of Band = ⅛ in.
Radial thickness of Belt = 1/16 in.

* Actual size of sleeve has been fixed by taking standard lead pipe as increasing by ½ in. up to diameters of 5 in., and over that by 1 in.

TABLE VII—(*continued*)

Cross-sectional Area of Conductor: sq. in.	Outer Diameter of Ferrule: 16th in.	Diameter over Taped Ferrule: 16th in.	Diameter over Banded and Taped Ferrule: 16th in.	Diameter over Bunched, Banded, and Taped Ferrules: 16th in.	Diameter over Belted, Bunched, Banded, and Taped Ferrules: 16th in.	Inside Diameter of Sleeve		Distance between Crutches: in.	Distance between Sheaths: in	Length of Sleeve: in.
						Calc. 16th in.	Actual * in.			
·06	7	12	16	35	37	45	3	12	13	14½
·1	9	14	18	39	41	49	3	13	14	15½
·15	11	16	20	43	45	53	3½	14	15	16½
·2	13	18	22	48	50	58	3½	15	16	17½
·25	14	19	23	50	52	60	4	16	17	18½
·3	16	21	25	54	56	64	4	17	18	19½
·4	18	23	27	59	61	69	4½	18	19	20½
·5	20	25	29	63	65	73	4½	19	20	21½

3,300 volts = Working Pressure of Cable.
Crutch to Sheath = ½ in.

Radial thickness of Tape round Ferrule = 5/32 in.
Radial thickness of Bands = ⅛ in.
Radial thickness of Belt = 1/16 in.

* *Ibid.*

TABLE VII—(*continued*)

Cross-sectional Area of Conductor: sq. in.	Outer Diameter of Ferrule: 16th in.	Diameter over Taped Ferrule: 16th in.	Diameter over Banded and Taped Ferrule: 16th in.	Diameter over Bunched, Banded, and Taped Ferrules: 16th in.	Diameter over Belted, Bunched, Banded, and Taped Ferrules: 16th in.	Inside Diameter of Sleeve		Distance between Crutches: in.	Distance between Sheaths: in.	Length of Sleeve: in.
						Calc. 16th in.	Actual * in.			
·06	7	14	18	39	42	50	3	13	15	16½
·1	9	16	20	43	46	54	3½	14	16	17½
·15	11	18	22	48	51	59	3½	15	17	18½
·2	13	20	24	52	55	63	4	16	18	19½
·25	14	21	25	54	57	65	4	17	19	20½
·3	16	23	27	59	62	70	4½	18	20	21½
·4	18	25	29	63	66	74	4½	19	21	22½
·5	20	27	31	67	70	78	5	20	22	23½

6,600 volts = Working Pressure of Cable.
Crutch to Sheath = 1 in.

Radial thickness of Tape round Ferrule = 7/32 in.
Radial thickness of Bands = ⅛ in.
Radial thickness of Belt = 3/32 in.

* *Ibid.*

TABLE VII—(*continued*)

Cross-sectional Area of Conductor:	Outer Diameter of Ferrule:	Diameter over Taped Ferrule:	Diameter over Banded and Taped Ferrule:	Diameter over Bunched, Banded, and Taped Ferrules:	Diameter over Belted, Bunched, Banded, and Taped Ferrules:	Inside Diameter of Sleeve		Distance between Crutches:	Distance between Sheaths:	Length of Sleeve:
						Calc.	Actual *			
sq. in.	16th in.	16th in.	16th in.	16th in.	16th in.	16th in.	in.	in.	in.	in.
·06	7	17	21	46	52	60	4	14	17	18½
·1	9	19	23	50	56	64	4	15	18	19½
·15	11	21	25	54	60	68	4½	16	19	20½
·2	13	23	27	59	65	73	4½	17	20	21½
·25	14	24	28	61	67	75	4½	18	21	22½
·3	16	26	30	65	71	79	5	19	22	23½
·4	18	28	32	69	75	81	5	20	23	24½
·5	20	30	34	74	80	88	6	21	24	25½

110,00 volts = Working Pressure of Cable.
Crutch to Sheath = 1½ in.

Radial thickness of Tape round Ferrule = 5/16 in.
Radial thickness of Bands = ⅛ in.
Radial thickness of Belt = 3/16 in.

* *Ibid.*

TABLE VIII—DIMENSIONS OF BRAID AND TAPE JOINTS

Similar to Fig. 29, Page 72

Cross-sectional Area of Conductor: sq. in.	Diameter over Braid Joint: in.	Diameter over Taped Braid Joint: in.	Diameter over Banded Taped Braid Joint: in.	Diameter over Bunched, Banded, Taped Braid Joints: in.	Diameter over Belted, Bunched, Banded, and Taped Braid Joints: in.	Inside Diameter of Sleeve		Distance between Crutches: in.	Distance between Sheaths: in.	Length of Sleeve: in.
						Calc. in.	Actual * in.			
·06	·56	·76	1·0	2·16	2·28	2·78	3	11	11·5	13
·1	·72	·92	1·16	2·5	2·62	3·12	3·5	12	12·5	14
·15	·82	1·02	1·26	2·72	2·84	3·34	3·5	13	13·5	15
·2	·94	1·14	1·38	2·98	3·10	3·60	3·5	15	15·5	17
·25	1·02	1·22	1·46	3·15	3·27	3·77	4	16	16·5	18
·3	1·08	1·28	1·52	3·28	3·4	3·9	4	18	18·5	20
·4	1·22	1·42	1·66	3·58	3·7	4·2	4·5	20·5	21	22·5
·5	1·33	1·53	1·77	3·82	3·94	4·44	4·5	21·5	22	23·5

660 volts = Working Pressure of Cable.
Crutch to Sheath = ·25 in.

Radial thickness of Tape round Braid Joint = ·1 in.
Radial thickness of Bands = ·12 in.
Radial thickness of Belt = ·06 in.

* *Ibid.*

TABLE VIII—(*continued*)

Cross-sectional Area of Conductor:	Diameter over Braid Joint:	Diameter over Taped Braid Joint:	Diameter over Banded and Taped Braid Joint:	Diameter over Bunched, Banded, and Taped Braid Joints:	Diameter over Belted, Bunched, Banded, and Taped Braid Joints:	Inside Diameter of Sleeve		Distance between Crutches:	Distance between Sheaths:	Length of Sleeve:
						Calc.	Actual *			
sq. in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
·06	·56	·84	1·08	2·33	2·45	2·95	3	12	13	14·5
·1	·72	1·0	1·24	2·68	2·8	3·3	3·5	13	14	15·5
·15	·82	1·1	1·34	2·89	3·01	3·51	3·5	14	15	16·5
·2	·94	1·22	1·46	3·15	3·27	3·77	4	16	17	18·5
·25	1·02	1·3	1·54	3·32	3·44	3·94	4	17	18	19·5
·3	1·08	1·36	1·6	3·45	3·57	4·07	4	19	20	21·5
·4	1·22	1·5	1·74	3·76	3·88	4·38	4·5	21·5	22·5	24
·5	1·33	1·61	1·85	3·99	4·11	4·61	4·5	22·5	23·5	25

3,300 volts = Working Pressure of Cable.
Crutch to Sheath = ·5 in.

Radial thickness of Tape round Braid Joint = ·14 in.
Radial thickness of Bands = ·12 in.
Radial thickness of Belt = ·06 in.

* *Ibid.*

TABLE VIII—(*continued*)

Cross-sectional Area of Conductor:	Diameter over Braid Joint:	Diameter over Taped Braid Joint:	Diameter over Banded, Taped Braid Joint:	Diameter over Bunched, Banded, and Taped Braid Joints:	Diameter over Belted, Bunched, Banded, and Taped Braid Joints:	Inside Diameter of Sleeve		Distance between Crutches:	Distance between Sheaths.	Length of Sleeve:
						Calc.	Actual *			
sq. in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
·06	·56	·96	1·2	2·59	2·75	3·25	3·5	13	15	16·5
·1	·72	1·12	1·36	2·94	3·1	3·6	3·5	14	16	17·5
·15	·82	1·22	1·46	3·15	3·31	3·81	4	15	17	18·5
·2	·94	1·34	1·58	3·41	3·57	4·07	4	17	19	20·5
·25	1·02	1·42	1·66	3·58	3·74	4·24	4·5	18	20	21·5
·3	1·08	1·48	1·72	3·71	3·87	4·37	4·5	20	22	23·5
·4	1·22	1·62	1·86	4·02	4·18	4·68	4·5	22·5	24·5	26
·5	1·33	1·73	1·97	4·25	4·41	4·91	5	23·5	25·5	27

6,600 volts = Working Pressure of Cable.
Crutch to Sheath = 1 in.

Radial thickness of Tape round Braid joint = ·2 in.
Radial thickness of Bands = ·12 in.
Radial thickness of Belt = ·08 in.

* *Ibid.*

TABLE VIII—*(continued)*

Cross-sectional Area of Conductor:	Diameter over Braid Joint:	Diameter over Taped Braid Joint:	Diameter over Banded and Taped Braid Joint:	Diameter over Bunched, Banded, and Taped Braid *Joints*:	Diameter over Belted, Bunched, Banded, and Taped Braid Joints:	Inside Diameter of Sleeve		Distance between Crutches:	Distance between Sheaths:	Length of Sleeve:
						Calc.	Actual *			
sq. in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
·06	·56	1·16	1·4	3·02	3·38	3·88	4	14	17	18·5
·1	·72	1·32	1·56	3·37	3·73	4·23	4·5	15	18	19·5
·15	·82	1·42	1·66	3·58	3·94	4·44	4·5	16	19	20·5
·2	·94	1·54	1·78	3·84	4·2	4·7	4·5	18	21	22·5
·25	1·02	1·62	1·86	4·01	4·37	4·87	5	19	22	23·5
·3	1·08	1·68	1·92	4·14	4·5	5	5	21	24	25·5
·4	1·22	1·82	2·06	4·45	4·81	5·31	6	23·5	26·5	28
·5	1·33	1·93	2·17	4·68	5·04	5·54	6	24·5	27·5	29

11,000 volts = Working Pressure of Cable.
Crutch to Sheath = 1·5 in.

Radial thickness of Tape round Braid joint = ·3 in.
Radial thickness of Bands = ·12 in.
Radial thickness of Belt = ·18 in.

* *Ibid.*

TABLE IX—DIMENSIONS OF SLIP ON UNDER OIL TUBE JOINTS

SEE FIG. 30, PAGE 77

Cross-sectional Area of Conductor: in.	Outer Diameter of Paper Tube: in.	Inside Diameter of Sleeve: in.	Distance between Crutches: in.	Distance between Sheaths: in.	Length of Sleeve: in.
20,000 volts—					
·06	1·4	5	31	36	38
·1	1·5	„	„	„	„
·15	1·6	„	„	„	„
·2	1·7	„	„	„	„
·25	1·75	6	34	39	41
·3	1·8	„	„	„	„
30,000 volts—					
·06	1·65	6	38	46	48
·1	1·75	„	„	„	„
·15	1·85	„	„	„	„
·2	1·95	„	„	„	„
·25	2·0	„	„	„	„

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